1987

Statistical assessment of vibration data in drilling.

Hui Kong. Lau
University of Windsor

STATISTICAL ASSESSMENT

OF

VIBRATION DATA IN DRILLING

by

Hui Kong Lau

A Thesis
Submitted to the
Faculty of Graduate Studies and Research
through the Department of
~~Mechanical Engineering~~ in Partial Fulfilment
of the Requirements for the Degree
of Master of Applied Science at
the University of Windsor

Windsor, Ontario, Canada

1987

ISBN 0-315-39613-X

ABSTRACT

A Tool wear monitoring procedure, using the vibration signals generated from the drilling process, was developed. The signals were assessed statistically by grouping the time-amplitude signals into frequency distributions and describing the characteristics of the distributions in term of their central tendency, dispersion, asymmetry and peakedness. Five statistical parameters were used, these being: mean, standard deviation, skew, kurtosis and RMS or height of the distribution. Two different drill sizes; 3.18 mm and 6.35 mm were used and experiments were performed on three machine-tools with operating conditions as close to the recommended values as possible.

Statistical results obtained were machine dependent and to some extent influenced by the type of drill wear taking place at the cutting edges. The results for the 3.18 mm diameter drill bits were promising and were reproducible. For the 6.35 mm diameter drill bits, the results were not very good..

The standard deviation, RMS of the distribution and kurtosis were found to be useful as potential descriptors for drill wear monitoring.

Dedicated to

my parents and sisters

ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to his research advisor, Dr. Z. Reif, for his supervision, patience and valuable suggestions throughout the period of this research and to Dr. R. Gaspar for his expertise and encouragement.

The author is grateful for the technical assistance of Mr. R. Tattersall and Mr. W. Beck, the Mechanical Engineering Department technologists. Special thanks are also due to Mr. Doug Chang, Mr. Francis Luk, Mr. John Chahine and other fellow graduate students.

The author wishes to thank his family members for their support and patience throughout the period of his studies in Canada.

This research is financially supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through grant number 9430.

CONTENTS

LIST OF FIGURES

Figure		Page

Figure Page

LIST OF TABLES

NOMENCLATURE

A = Real area of contact between the tool and workpiece.

A/D = Analog to digital conversion.

Acc. = Accelerometer.

attn. = Signal attenuation.

BUE = Built-up edge.

C = Chisel edge length.

Cw = Crater wear.

Cew = Chisel edge wear.

D = Drill diameter.

Ds = Sampling interval delay.

d = Unworn portion of the drill along the cutting lips.

EU = Engineering unit.

F_i = Frequency of occurrence in i^{th} class. ($i=1,2,...N$)

Fw = Flank wear.

Fz = Principal cutting force.

HSS = High speed steel.

Hb = Material hardness.

h = Sampling interval.

M = Torque.

Mr = r^{th} moment of the distribution.

Mw = Margin wear.

N = Total number of classes in a statistical distribution.

RMS = Root mean square height of the distribution.

RPM = Spindle speed.

SD = Statistical/raw data.

SR = Statistical results.

s = Feed rate.

ST. DEV. = Standard deviation.

T = Thrust.

V = Drill speed.

Vib. = Vibration.

X = Mean value of the statistical distribution.

X_i = Classes. (i=1,2,... N)

γ = Included angle.

θ = Chip-tool interface temperature.

μ_3 = Skewness of the statistical distribution.

μ_4 = Kurtosis of the statistical distribution.

σ = Standard deviation.

Chapter I

INTRODUCTION

Drilling is the most widely used manufacturing operation and the most economical method of hole production in industry today. It is the type of manufacturing operation which is absolutely indispensable for production of machine parts and many other components [52]*. Billions of holes are drilled each year and it is estimated that the cost of circular hole cutting tools in the United States alone exceeds $200 million annually and accounts for about one-third of all metal-cutting operations [2]. It is, however, also one of the most troublesome operations due to the complex tooling used and the cutting mechanics involved at the cutting zones. Therefore, in order to improve the productivity and quality of the manufacturing processes and the automation of the machine, a fundamental need is to have accurate and continuous knowledge of the tool's condition (on-line information).

The drill, the basic hole-producing tool, is of ancient origin and was one of man's earliest machining achievements. In fact, the need for such a tool has been so great that we can find drills of one type or another in nearly all civilizations for which there is any recorded history. Nevertheless, the first

* Numbers in parentheses refer to cited references.

machine-made twist drills were not produced until about 1860, and truly modern twist-drill development begins with the invention of high speed steel around 1900 [51,60].

Because of its importance in nearly all production operations, twist-drills have been the subject of research for years. The basic design and the general configuration of a twist-drill, as shown in Figure 1.1, has remained virtually unchanged. The cutting elements consist of two main cutting edges (or lips) lying in parallel planes displaced from each other by the distance equal to the thickness of the web. These are connected by a chisel edge which is formed by the intersection of the flank surfaces extending rearwardly from the main cutting edges.

Twist drills are manufactured in a variety of styles and in many different sizes. Figure 1.2 illustrates some of the more commonly used conventional and special-purpose twist drills. Based on sales of more than 50 million standard twist drills, the statistics compiled by National Twist Drill shows that a median of 90 % of all sales fall between 1.27 and 10.16 mm in diameter and with 3.2 mm diameter being the most popular type [12,19].

The geometrical shape of the drill point is not efficient in cutting due to lack of centering, poor cutting action at the centre and also varying load along the cutting edges. Those basic problems have long been recognized and have been the subject of numerous investigations [4,8,20,31,41,43,63].

In this research, the main emphasis is not on finding a new concept in the drill point geometry but on monitoring the

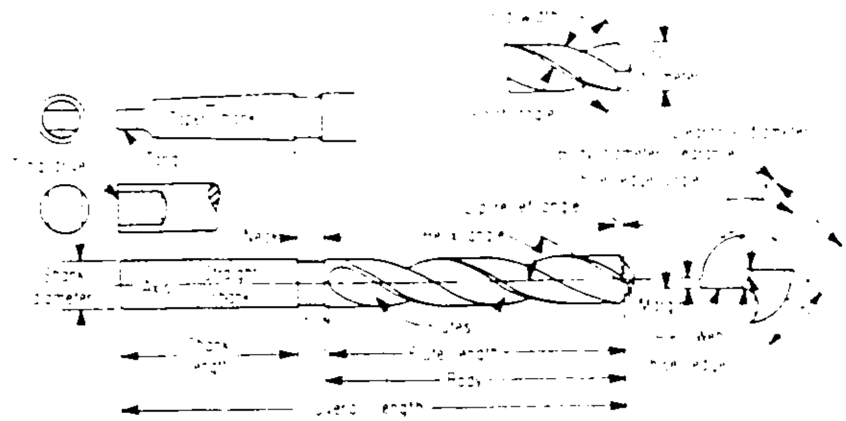


Figure 1.1 Standard terms used to describe elements of twist drills.

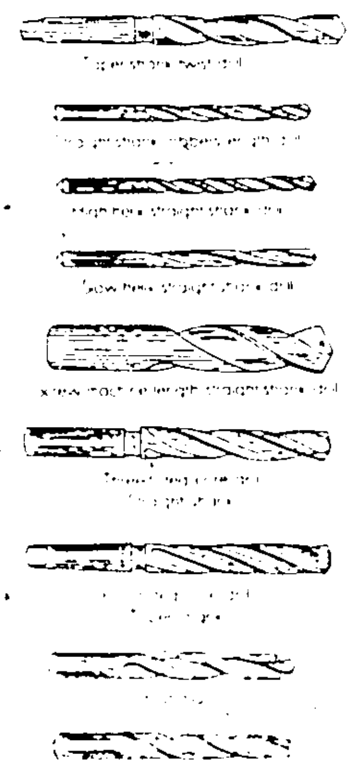


Figure 1.2 Some conventional and special-purpose twist drills.

drill conditions during the process of drilling ("in-process") and to predict tool-life through statistical means. However, some of the findings concerning the effect of drill geometry, operating conditions (speed and feed rate), and the tool and workpiece selection on the performance of the drill will be reviewed in the literature survey. These findings will help in a better understanding of the mechanism of the drilling process.

The need for such an "in-process" system has traditionally resulted from the desire to cut down on downtime which may arise either due to unexpected tool failure or routine inspection for wear. In recent years, with the increased use of expensive, high volume, multiple tool machining systems like transfer lines and automatic machining centers, it has become essential to have a system that could monitor and predict tool failure in order to increase machine-tool efficiency and stay competitive in this high technology computer-based world. An added need for research in this area is due to advances in adaptive control and Computer-Aided-Manufacturing. It is to those machining systems at which this research is aimed.

The common practise with the tool-replacement in industry is often based on the following criteria:

1). After a predetermined number of cuts or certain time; or
2). Replace all at the time of the shortest-lived tool.

The above practices are by no means efficient and lead to severe under-utilization of tools in most cases due to the fact that significant differences in tool life exist even in nominally identical new tools. The large scatter of tool life has been shown to be due to the production tolerances in manufacturing [32,34]. If a tool is changed before the end of its economical life, it will not only increase the tool-change time but will also increase capital cost. In summary, it can be stated that an effective wear monitoring procedure will significantly increase, particularly in untended manufacturing, productivity and quality control.

Machine-tool vibration was chosen as the parameter for tool wear monitoring, mainly because it was proven to be reliable, easy to implement and also cost effective [2,49,75]. Monitoring of tool wear, generally, will give invaluable information about the tool's condition and it is the extent of wear on the cutting edges which determines the tool life.

Tool wear is a very complex phenomenon. It is difficult to monitor because it depends on numerous factors, including type of drill, size, shape and point style, operating conditions, such as speed and feed rate, workpiece hardness, microstructural changes, lubricant, etc [6,19]. In drilling operations, generally there are seven dominant types of wear taking place at the active cutting zone of the drill, namely, tip wear, outer corner wear, flank wear, crater wear, margin wear, chisel edge wear and chipping at the cutting edges [34]. These are shown in Figure 1.3. The severity of each type of wear is significantly influenced by the speed of operation, feed rate, and tool and workpiece configuration.

Knowing that drilling is the most popular hole-production method used in industry today, and the importance in the development of a reliable and efficient tool wear monitoring system for use in high volume, multiple tool machining systems, and in a Computer-Integrated-Manufacturing environment, the objective of this research is:

> To study the feasibility of developing a tool wear monitoring system based on the evaluation of statistical discriptors applied to the vibration signal generated during the drilling operation.

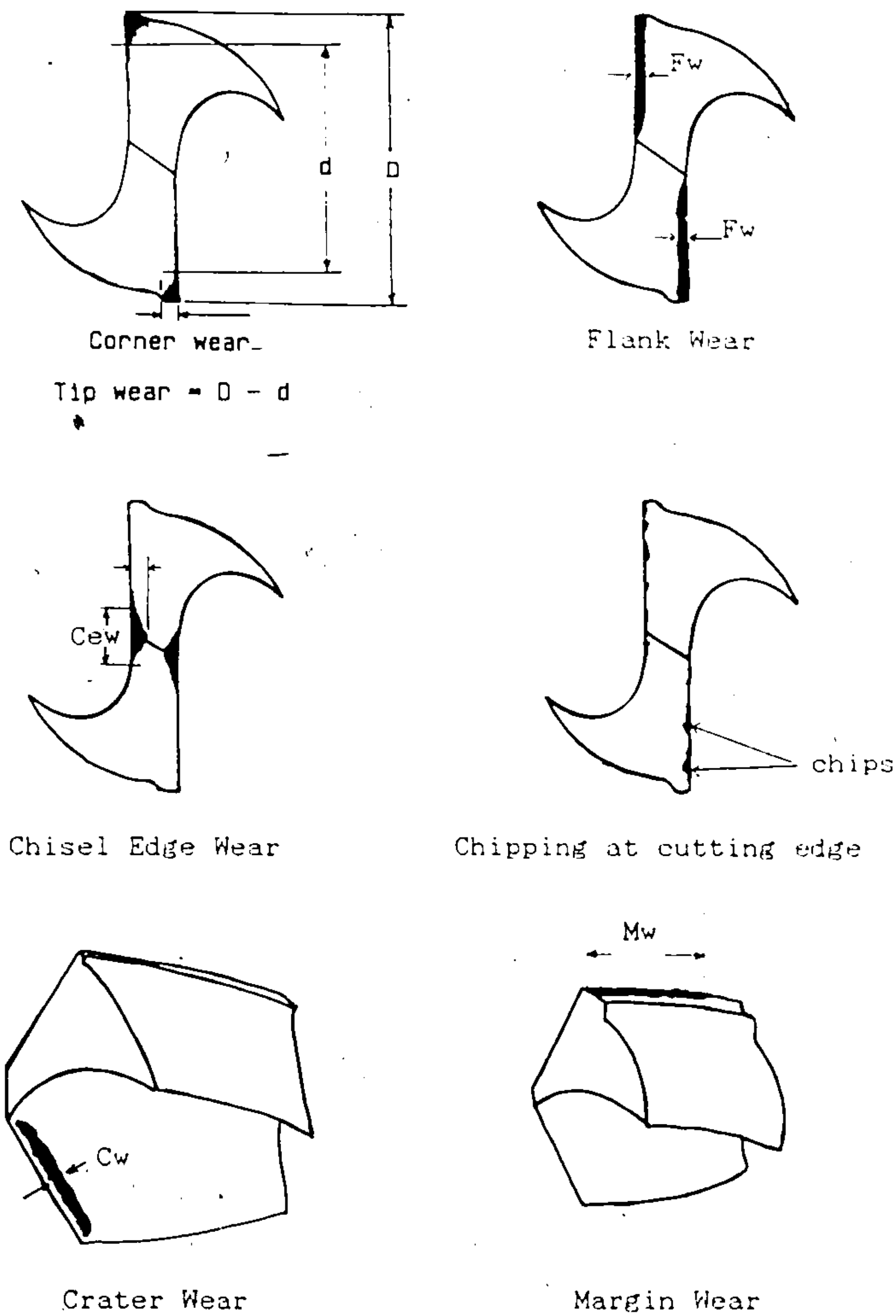


Figure 1.3 Different types of wears.

Chapter II

LITERATURE SURVEY

The objectives of this chapter are to give an overview of: the drilling process, the mechanisms and factors affecting tool wear, and finally, available methods of tool-wear sensing.

2.1. Drilling.

Drilling is generally applied where precision work is not the prime concern. Its main advantages are a high penetration rate and longer tool life.

As mentioned in Chapter I, drilling is the most important machining operation in metal-cutting industry today, however, it involves the use of a tool, for which not only the basic mechanics of the cutting action are complex but are also not adequately understood. Because of the geometrical shape of the twist drill, complicated cutting action takes place at the drill point, with different radii of the cutting edges subjected to different cutting conditions.

The basic cutting action can be summarized by the following steps: a small hole is pierced by the rotating web, metal chips are formed by the rotating edges (lips) and are ejected through the flutes, and finally the drill is guided in the hole already produced by the margin.

The drill geometry represents a compromise of several conflicting requirements, which include:

1). A small web to reduce thrust on the drill but a larger web for greater resistance to chipping and greater torsional rigidity.

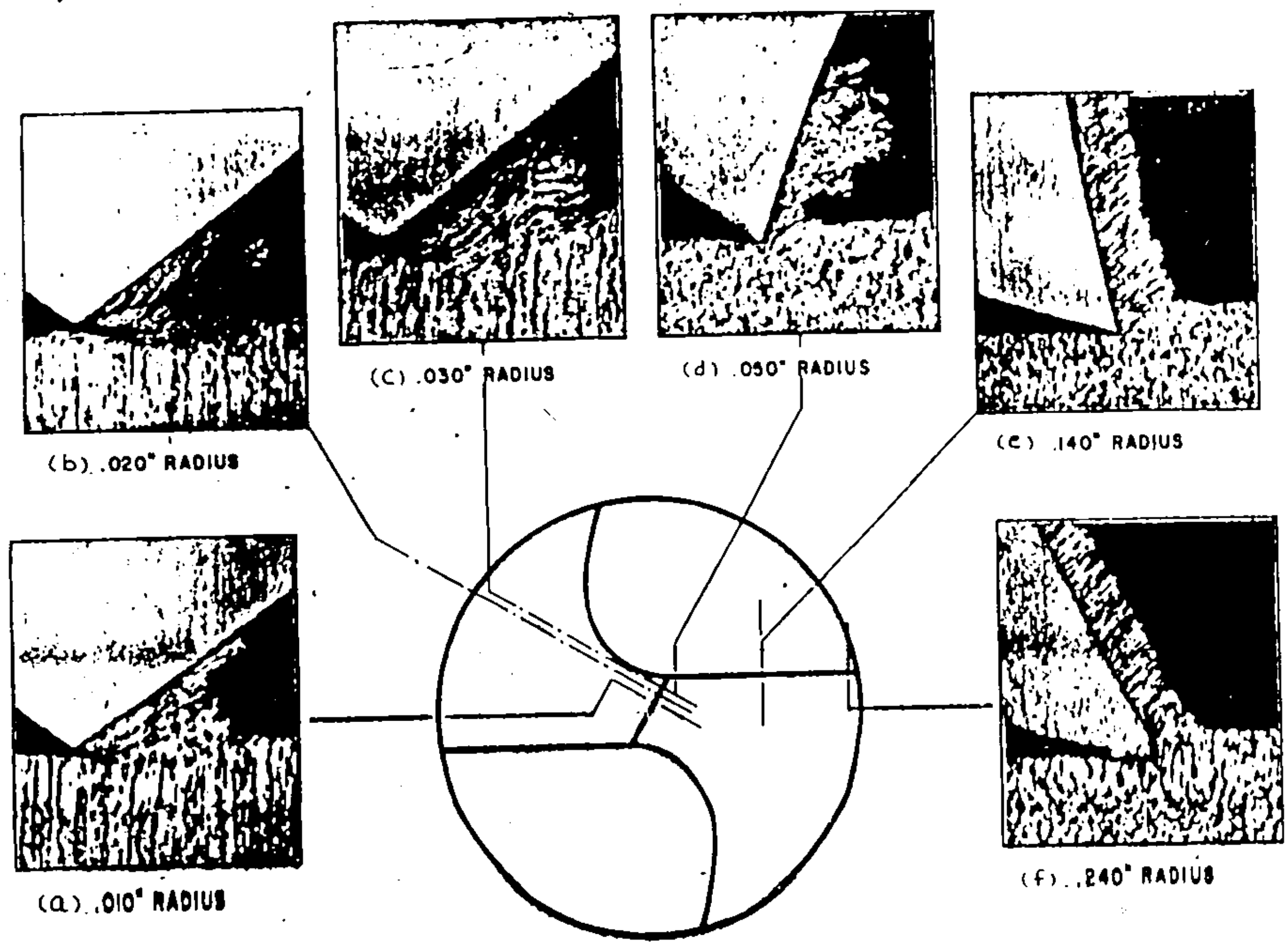
2). Large flutes to provide a larger space for chip transport but small flutes for better torsional rigidity.

3). An increase in the helix angle to remove chips quickly but a decrease in the helix angle for a greater length of the cutting edges.

Less obvious compromises are associated with the choice of the geometric parameters that influence the effective rake and relief angle.

2.2. Mechanics of the drilling process.

Oxford and Shaw [51], using the quick-stop technique, were able to freeze the cutting action through a rapid stop of the relative motion between the drill and the workpiece. They found that the chip-formation mechanism along the cutting edges (lips) of a twist drill appears to be basically the same as for any other single-point metal-cutting operation as shown in Figures 2.1(d,e,f) [20,51,76]. However, that under the chisel edges was quite complex, as can be seen in Figures 2.1(a,b,c). At the very center of the drill point, the only tool velocity is that of the feed in the axial direction and the deformation of the metal resembles that caused by a indenting punch. Toward the sides, deformation becomes more complex and more severe because of the combination of rotational and feed velocities.



CHISEL POINT DRILL

Figure 2.1 Series of photomicrographs of sections through chisel point drill and partly formed chips at successive points along cutting edge from axis to periphery.

2.2.1. Parameters that influence cutting forces.

Cutting forces that are generally of interest in most cases are the thrust and torque. In order to evaluate them, three actions at the cutting and chisel edges have to be considered. There are, as mentioned before, cutting actions at the lip and chisel edges, and the extrusion action at the chisel edges. The extrusion process has a negligible effect on the drill torque but is significant in influencing the drill thrust [61].

In general, quantities that influence the cutting forces are: work material and structure, drill diameter, helix angle, web thickness, point angle, number of cutting edges, speed, feed rate, and drill sharpness [12]; however, the effect of each can be different. For instance, the web thickness of the drill is found to influence the thrust and torque significantly, but the effect of the helix angle is found to be less important. On the other hand, the helix angle does play an important role in influencing the forces when chips start to jam in the flute.

In general, a harder workpiece material, a decrease in the drill sharpness, larger drill diameter, and higher feed rates will tend to increase the cutting forces. Depth of cut and cutting speed have a negligible effect, particularly when the cutting speed is within the commercial range, i.e. greater than 60 feet per minute (fpm) [9].

For standard drills, where the ratio C/D is about 0.8, the expression for the torque and thrust are:

$$M = 0.087 * Hb * s^{0.8} * D^{1.8}$$

$$T = 0.195 * Hb * s^{0.8} * D^{0.8} + 0.0022 * Hb * D^{2}$$

where, M = thrust.(lb)

T = torque.(in-lb)

C = chisel edge length.(in)

D = drill diameter.(in)

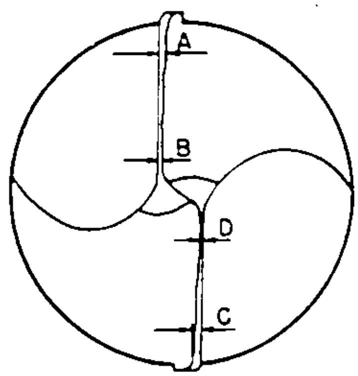
s = feed rate.(in/rev)

Hb = material hardness.(BHN)

The two above empirical equations generally agree with those presented by other investigators [9,12,61].

With wear occuring at the drill-point, different characteristics of the cutting forces are observed. Subramanian and Cook [65] were able to predict the relations of thrust and torque with hardness of work material, feed rate, diameter of the drill and also the quantity termed average flank wear as shown on Figure 2.2. Those relations were observed in drilling cast iron using high speed steel (HSS) drills of 10.32 mm diameter at 690 rpm.

Generally, in a drilling process, two directional movements are observed, one in the cutting direction (contributes to torque), and the other in the feed direction (contributes to the thrust). Figures 2.3(a),2.3(b), show the two categories of drill cutting defect. Figure 2.3(a), shows the wear type which



$$\text{FLANK WEAR} = \frac{A + B + C + D}{4}$$

Figure 2.2 Average flank wear.

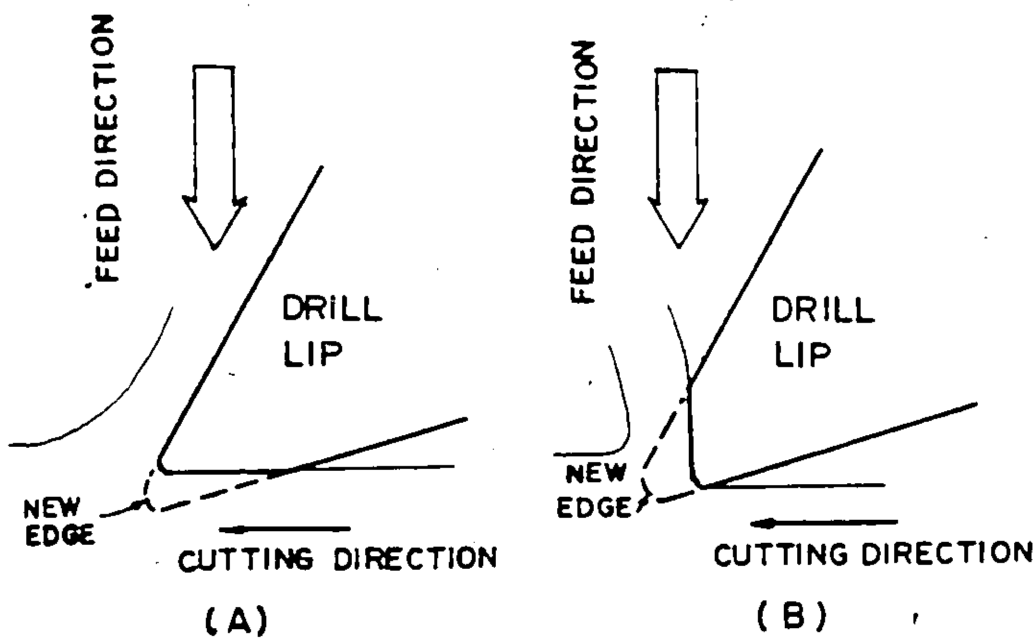


Figure 2.3 Two categories of the drill cutting edge defects.

has more effect on thrust force, namely, defects includes chisel edge wear, flank wear, and partly corner wear. Figure 2.3(b), shows the wear type which has more effect on the torque and includes defects such as breakage, crater wear, and outer corner wear.

2.2.2. Effect of built-up edge.

The build-up at cutting edges occurs in all but a few exceptional cases. Because it alters the tool angles, it influences cutting forces, cutting temperatures, tool life, and other elements of the drilling process. Generally, with the presence of the built-up edge (BUE), the values of the cutting force will decrease due to the increase of effective rake angle. It also has significant influence on the surface finish of the product because as the BUE grows forward, it will usually also grow downward, causing the finished surface to be undercut, which degrades the quality of the finish, as can be seen in Figure 2.4. Built-up edge has a more pronounced effect near the chisel edge than at the cutting edges [15,29]..Figure 2.5 shows how the principal cutting force varies for several feeds and also the type of built-up edge formed with speed [47].

2.3. Factors affecting tool wear.

Tool wear is an important phenomenon in metal cutting since it affects significantly the economics of the cutting process. It is unavoidable due to the interactions between the tool and the workpiece on one hand and the chips and the

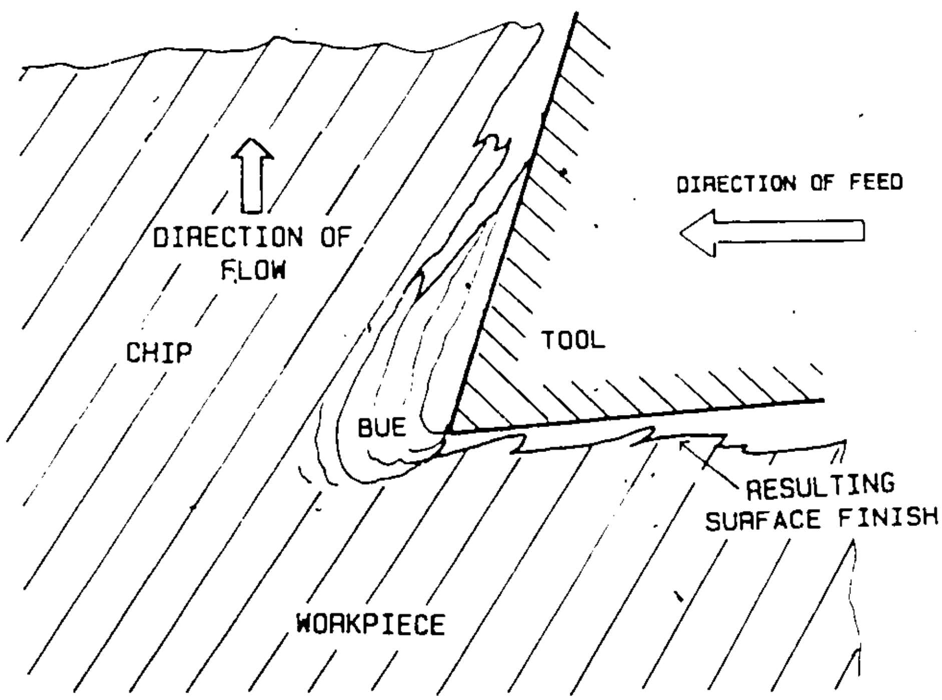


Figure 2.4 Effect of bulit-up edge (BUE) on the surface finish of the product.

tool on the other. Knowledge of the mechanisms and factors involved helps in the optimization of the production process. In order to optimize, it is necessary to determine the optimal time to replace the tool, which is refered to as tool-life. Tool wear and tool-life are closely related and it is the extent of wear that determines whether a tool has reached the limits of its economical life or not.

The main cause of wear is the increased temperature in the tool due to the transformation of mechanical work into heat during the cutting operation. It has been found that over 98 percent of the power used in machining goes into heat [11,13]. The two main sources of heat at the cutting edge are the shear zone, where the metal of the workpiece is being formed into a chip, and the tool-chip interface, where the chip rubs against the cutting tool as shown in Figure 2.6.

There are several forms of wear in twist drills, such as flank wear, crater wear, chisel edge wear, outer corner wear, tip wear, margin wear, and chipping at the cutting edges as mentioned before. The severity of the wear depends on the operating conditions. It has been determined that wear starts ~~at~~ the outer corners of the cutting lips and thus it can be used as a performance index because of the relative ease of measurement and its close relationship with the drill life [34]. In fact, twist drills most commonly fail because of wear at the cutting lips. The mode of failure is inherently temperature dependent, if abusive cutting conditions leading to drill breakage of the chisel edge failure are excluded [60].

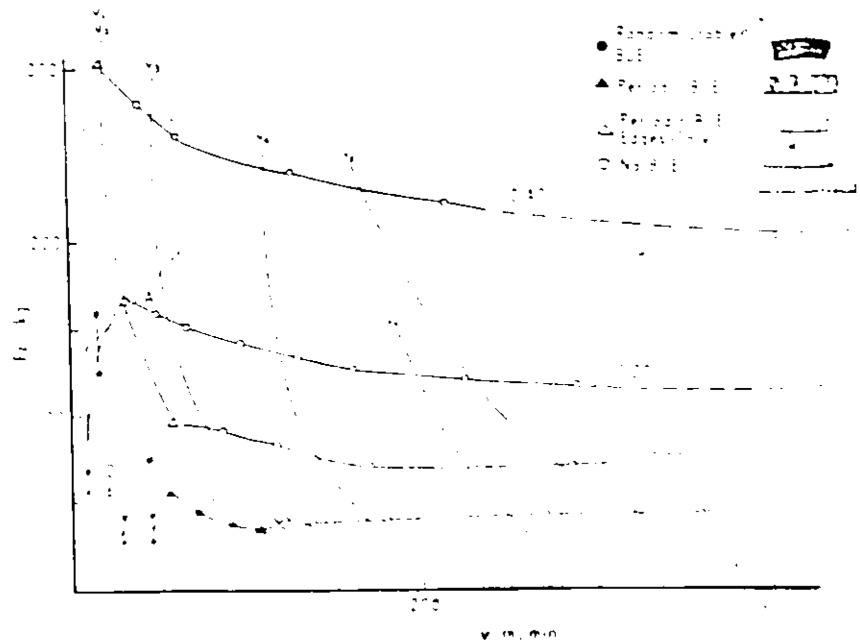


Figure 2.5 Variations of the principal cutting force with cutting speed for several feeds.

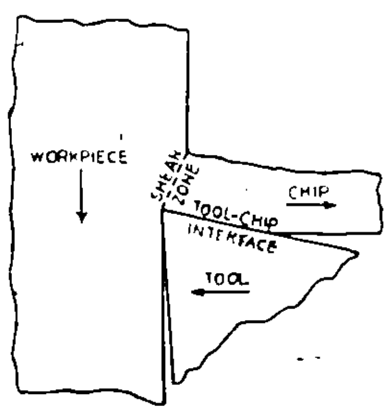


Figure 2.6 The energy regions in metal cutting.

2.3.1. Influence of cutting speed on temperature.

Heat is predominantly generated at the shear zone. As the tool moves through the workpiece, the shear zone appears to the tool as a stationary heat source moving ahead of the tool at the same rate as the tool travels through the workpiece. Heat from this stationary source is conducted in both directions either out with the chips or it remains in the workpiece thus raising its temperature. At high cutting speeds, the tool moves so rapidly that far less heat is conducted into the workpiece, and therefore most of it is taken off with the chips. This will increase, through the tool-chip interface, the temperature of the tool, in addition to the increased frictional interaction between the chip and the tool, as can be seen in Figure 2.7. The maximum chip-tool interface temperature is observed to occur at about two-thirds of the way back from the cutting edge to the point where the chip curls away from the tool [34]. Figure 2.8 indicates this phenomenon. This high chip-tool temperature will promote crater wear on the tool face. Despite the high chip-tool interface temperature, only small amounts of heat were found to be transfered to the tool or the workpiece. Conversely, large amounts of heat were found to flow into the cutting tool when it was operated at low cutting speeds and high feed rates.

2.3.2. Influence of feed, depth of cut, and work material on temperature.

Increasing the feed rate will cause an increase in

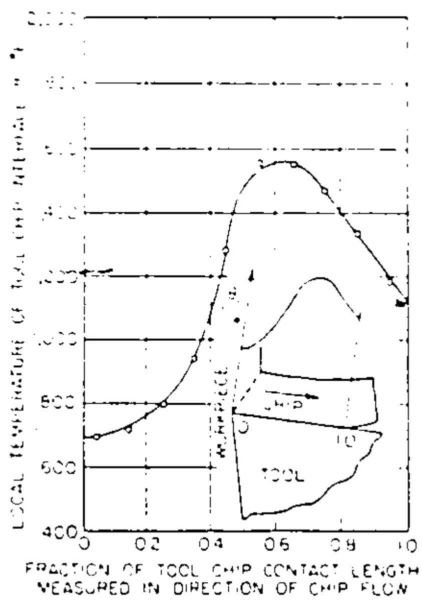


Figure 2.7 Temperature distribution on the tool-chip interface.

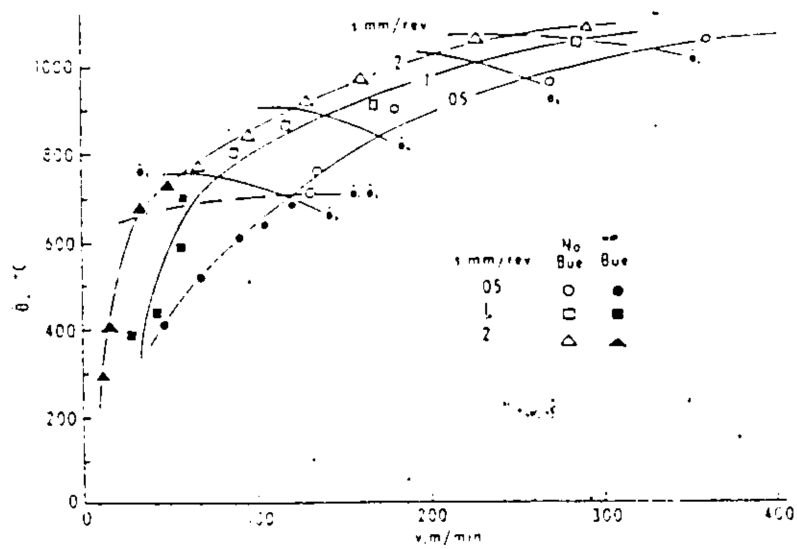


Figure 2.8 Values of the tool-chip interface temperature at different cutting speeds and feeds.

the interface temperature and heat generation. The depth of cut will generally not increase the interface temperature except through redistribution of the heat flow into the cutting edges. If a workpiece of higher hardness is used, increased work is needed to form and remove the chip, which brings about a higher interface temperature and hence increases the tool wear.

Other added factors, which most likely will influence tool wear other than the few mentioned above, are the grain and structure of the work material, built-up edge (BUE), surface layer of cutting tool and workpiece, relative hardness of the tool and work material, cutting edge sharpness, lubrication or coolant.

2.4. Mechanisms involved in tool wear.

Noticeably, there are four basic mechanisms which can operate singly or in various combinations to produce tool wear. These four mechanisms are adhesive wear, abrasive wear, electrochemical wear, and diffusion wear [70,77]. The predominance of a particular mechanism or some combinations will depend predominantly, on the cutting temperature and the properties of the tool and workpiece materials [37]. At low temperatures, mechanical wear processes, such as abrasion and adhesion, are rate-controlling and the wear of the tool material is determined primarily by its hardness. At higher temperatures, the wear rate is predominantly determined by the chemical properties of the tool-workpiece material, hence diffusion wear will be the major type [1].

2.5. Tool wear sensing techniques.

The monitoring of tool wear requires the development of very sensitive, accurate, and reliable techniques. It was not until recent years that much attention has been focused on the development of so call "in-process" tool wear monitoring systems. The recently increased interest in this area can be largely related to the advent of stand-alone microprocessors and powerful microprocessor-based analyzers, which rapidly and cost effectively perform the data analysis and evaluation, which otherwise would be impossible.

Numerous sensing technologies are used in industry today. They can be broadly categorized into direct and indirect methods. Direct sensing methods are those that utilize effects caused directly by tool wear. They include direct measurement of wear by means of optical scanning, electrical resistance, and radioactive techniques; measurement of tool geometry, change of workpiece size, and analysis of tool wear particles in the chips. On the other hand, indirect sensing methods, involve keeping track of one or more parameters and correlating changes in them to changes in tool wear. These include measurement of driving power, forces, machine tool vibration, and temperature. Generally, they are much easier to implement.

In order for the sensing technique to be effective, it should provide the following characteristics:

1). Direct correlation with the signal describing the trend of the parameter with tool wear.

2). Minimal delay in the sensing process and a practically instantaneous reaction to tool failure.

3). It must be capable of providing reliable tool wear trend data as well as being sensitive to sudden changes in the cutting operation.

4). It must be adaptable to the production floor without posing any difficulties to the machining operation and maintenance.

5). Technique has to be reliable.

6). The system has to be capable of withstanding without damage the hostile working environment.

7). Has to be cost effective.

The techniques reviewed are not all truly "in-process" because they involve measurements between cuts, as opposed to measurements during machining process.

2.5.1. <u>Direct methods.</u>

These method are generally, difficult and sometime impossible for "in-process" monitoring, especially where there is a continuous contact between the tool and workpiece.

2.5.1.1. <u>Radioactivity.</u>

This method involves measurement of the volumetric overall loss of the tool material. The entire tool or only the drill-point are made radioactive by irradiating it in a nuclear reactor. Since amount of wear from the drilling process is small, the total activity of the tool has to be high, which calls for extreme precautions in the handling and analysing of the chips or the wear particles. This technique is very inconvenient and is therefore confined to a few research applications [3]. It is also unlikely to be accepted by workers' unions.

2.5.1.2. Direct wear measurement.

This method involves the interruption of the drilling process at intervals, taking the tool out, and measuring the wear under an optical microscope. It has the disadvantage that the cutting process is interrupted in a way that it would not be acceptable during normal production. The measuring process is lengthy and tedious, and the judgement of the position of the worn edge is difficult and subjective. Strictly speaking, it is an off-line method. Generally, it is used for research purposes where detail deterioration of the tool at stage is needed for evaluating tool performance.

2.5.1.3. Optical sensing.

This method involves the use of the principle of light reflection, and equipment such as fibre optics and TV cameras. It usefulness in application as an in-process method is limited to intermittent cutting operations. It analyses the image of the wear zone either by sending the image into a image analysing computer or displaying it on TV monitor for manual inspection. Reliability of this system is very much in question, it is too slow for "in-process" applications and also technical expertise is required which makes it very expensive to implement. Another approach in this same context is utilizing the different light reflection behaviour between the worn and unworn area of the cutting edges [48].

Its application is limited because of its relative slow speed, inaccessibility of the cutting edges, presence of coolant mist and hostility of the cutting environment.

2.5.1.4. Electrical resistance.

This method utilizes the reduction in the electrical resistance across the tool-workpiece junction which occurs due to tool wear and the resulting increase of the contact area with the workpiece. The dependance of this contact resistance on changes in cutting parameters such as speed, feed, cutting forces, and temperature makes this appoarch unsuitable in many applications. However, it has been used successfully to measure tool wear in-process for a range of cutting conditions typical of finishing and turning on a lathe [48].

2.5.1.5. Chemical analysis.

It involves the collection of chips from both the tool and workpiece, separation of tool material and workpiece material by some chemical process, and correlation of wear with the volumetric loss from the tool. It is not a very suitable method for "in-process" monitoring.

2.5.2. Indirect methods.

Because of the difficulties encountered in implementing the direct methods, for "in-process" tool wear monitoring, the need exists for developing indirect methods of monitoring the tool wear.

2.5.2.1. <u>Sensors based on measuring forces or torques.</u>

It is one of the easier methods to implement. This method often utilizes the changes in some component of forces, such as feed force, thrust force, and drilling torque, and correlate it to tool wear. Problems arise when these force components are not constant but vary randomly, in which case mean values have to be used.

It was found that variations in the cutting forces that result from gradual tool wear, are often too small for sufficiently accurate and reliable measurements of wear [48,49].

2.5.2.2. <u>Temperature.</u>

As a cutting tool becomes dull, the ~~frictional~~ effect at the cutting edges increases, which then brings about the increase in the temperature. Using this fact, correlation of a temperature with tool wear can be developed.

The cutting temperatures measured with a thermocouple are very sensitive to the chemical composition of the tool-workpiece junction. This requires that the thermocouple be calibrated for every tool workpiece pair which is rather time consuming and uneconomical in a high production environment. Infrared temperature measuring systems, on the other hand, are expensive, complex, and difficult to focus. The main problems are focusing onto the area of interest and an inability to use these systems in the presence of cutting fluids.

2.5.2.3. Roughness of machined surfaces.

As the tool becomes dull, the resulting machined surface will be rougher. Hence, the degree of roughness of the machined surface can thus be used to correlate with the tool wear. This approach has not been very popular because changes in the surface finish could be due to chatter vibration, the machine tool structure, and also extraneous vibrations from other sources [48].

2.5.2.4. Measurement of workpiece dimensional changes and distance between tool post and workpiece.

During the cutting operation, as the tool wears, the distance between the tool post and the workpiece decreases, and also brings about some changes in the workpiece dimension. Generally, those measurements are prone to errors resulting from [48]:

1). Expansion of the workpiece and cutting tool as temperature rises.

2). Vibration or deflection of the tool or the workpiece due to the increase in cutting force as the tool wears.

3). Inaccuracies in the machine tool structure.

2.5.2.5. Acoustic Emission.

Acoustic emission is defined as a high elastic stress wave release from the material, when undergoing plastic deformatiom or fracture [16]. It is a type of high frequency vibration. Typically, the frequency of the signal is in the range from 100 kHz to 2 MHz. Its application to tool wear monitoring has a few advantages over other methods, namely, it is quite easily adapted to computer control, the frequency of the signal is well beyond the frequency range of the noise from the machine tool dynamics and extraneous sources, the signals are generated by processes in the cutting zone and can therefore be directly related to tool wear [18].

The study of acoustic emission in metal cutting has been a topic of extensive research by numerous researchers [16,17,18,49] and there have been noted success in sensing tool wear via acoustic emission analysis [49]. It is a relatively new nondestructive testing technique and has been also applied to monitor the structural integrity of aerospace and petrochemical structures, bridges and power plant components; to locate leaks and loose parts; and to verify quality of welds on line [28].

It does appear to be of great promise, however there are several problems that need to be overcome first before it can be used as part of a "in-process" tool wear monitoring system. Firstly, the understanding of the source characteristics is still very much incomplete, even though many theoretical explorations have been made. Those theories are either qualitative descriptions or simplifications difficult to prove or disprove experimentally. Secondly, the signal analysing process involves uses of additional and expensive equipment.

2.5.2.6. Vibration.

Vibration analysis is fast becoming a very prominent preventive and predictive maintenance tool for a wide variety of industrial equipment. It has been successful in reducing catastophic failures, maintenance cost and downtime, it provides advance warning of impending breakdown of machinery and increases the production rate [26,46,58].

Vibration is also used as a sensing medium in monitoring tool wear in metal cutting operations. Several authors [54,66,75], have investigated the correlation of machine tool vibration with tool wear. They all agree that as the tool becomes dull, the rubbing action between the tool and workpiece increases, which brings about an increase in the vibration level. The vibration signals can be easily monitored, and information can be analysed in a number of ways, either in the time domain or in the frequency domain.

According to [2], the machine tool vibration in a drilling process, analysed either in the time domain or the frequency domain, shows a definite sensitivity to tool wear. With the proper selection of the mode of vibration, the deterioration of the drilling process can be easily monitored [55,64].

Publications are sparse in the field of vibration as a basis of "in-process" monitoring. A possible explanation could be due to the lack of ability to identify frequency domain spectral peaks with drilling mechanics.

Time domain analysis of the vibration signal has indicated, at least in one study, that it can be utilized to detect improper drilling sequence, tool wear and to predict drill breakage [35].

This method has advantages which include: the ease of installation, durability and reliablity of the vibration pick-up by transducer. In addition, it can also pick up faults in the machine other than those due to the drilling process alone.

As can be seen from the above discussion, numerous tool-wear sensing techniques have been developed throughout the years, either applied on-line or off-line, however, none of these methods is universally accepted for all industrial applications. The foregoing problems have prompted this attempt to develop a tool-wear monitoring system by assessing statistically the vibration data generated during the drilling process. The analysis is done purely in the time-amplitude domain, i.e., the vibration signal is manipulated as a function of time only.

Chapter III

EXPERIMENTAL DETAILS

The main objective of this chapter is to provide a description of the experimental procedure and equipment used in this project. It involves: equipment, tools, workpiece selection and preparation, accelerometer selection and location, operating procedures, tape recording of data and wear measurements.

3.1. Equipment selection.

Drilling machines are available in many different types, sizes, and capacities. In this research, three lathes were selected for study, mainly due to their ability and capacity to deliver the recommended speed and feed rates for the drilling operations. A lathe was chosen over a drill press because it can deliver a constant feed rate. Rather than having the drill rotate, it was held stationary in a chuck and the workpiece was rotated. This arrangement is different from the usual practice of having the workpiece held stationary while drill is being rotated and fed, but the difference in the mechanics involved is belived to be minimal [57]. The three types of lathes used were Harrison M400, Colhester Master 2500, and Okuma type LS.

Accelerometers were used as vibration pick-ups. Their location was selected as close to the drilling action as possible to ensure the predominance of vibration from the drilling operation. Two different types of accelerometers were used to suite the type of tape-recorder. Table 3.1 gives specifications

TAPE RECORDER :			
Type	:	B&K 7005	Nagra IV SJ
Frequency Range	:	0 to 60 kHz	2.5 to 35 kHz
Weight	:	8.8 kg(19.4 Lbs)	7.3 kg(16 Lbs)
Recording Speed	:	38.1 cm/s	38.1 cm/s
Attenuation/ Gain setting	:	depends on drill size.	
3.18 mm	:	gain 10 db	attn. 50 db
6.35 mm	:	gain 1 db	attn. 55 db
ACCELEROMETER :			
Type	:	B&K 4348	PCB 307A
Sensitivity (mv/g)	:	8.39	100
Resonant frequency (Hz)	:	62,000	>40,000
Frequency Range (Hz)	:	0 to 20,000	2 to 10,000
Weight (gm)	:	11	31
Amplifier/power unit used	:	Vibration unit ZM 0060	480B power unit

Table 3.1. Tape-recorders and Accelerometers used.

of the two accelerometers and tape-recorders used in this project.

3.2. Drill and Workpiece selection and preparation.

Selection of the drill and workpiece combination not only gives a rough idea of the operating speed and feed rate required for proper cutting but also some insight into the mechanism involved, such as heat generation, type of chip formed, etc. Since the use of high speed steel (HSS) drill is so common in industry and because of its ability to retain high hardness at high temperature (hot-hardness) while maintaining good wear resistance, this type of tool was chosen for this research. Figure 3.1 and Figure 3.2 show, respectively, the hot hardness and recovery hardness for several types of cutting tool materials. The selection of the drill size for this research was made on the basis that smaller drill sizes are used more often than larger sizes. The mean size range for all twist drills produced would probably be around 4 mm [12,19]. Two drill sizes were used, namely 3.18 mm (1/8 in) and 6.35 mm (1/4 in). Table 3.2 gives the drill specifications and those dimensional tolerance are also included in Table 3.3.

The workpiece materials were selected on the basis of trial and error. After investigating a number of materials, AISI 4340 alloy steel was found to be most desirable due to its ease of machinablitily. Under the recommended operating speed, the

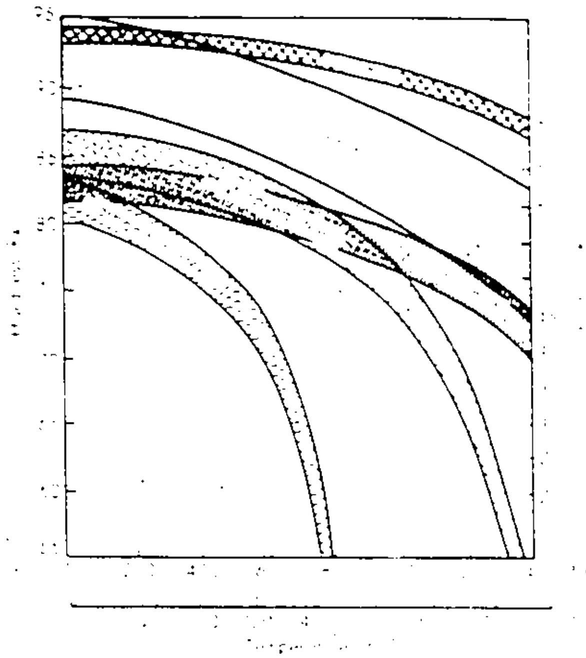


Figure 3.1 Hot hardness for several types of cutting materials.

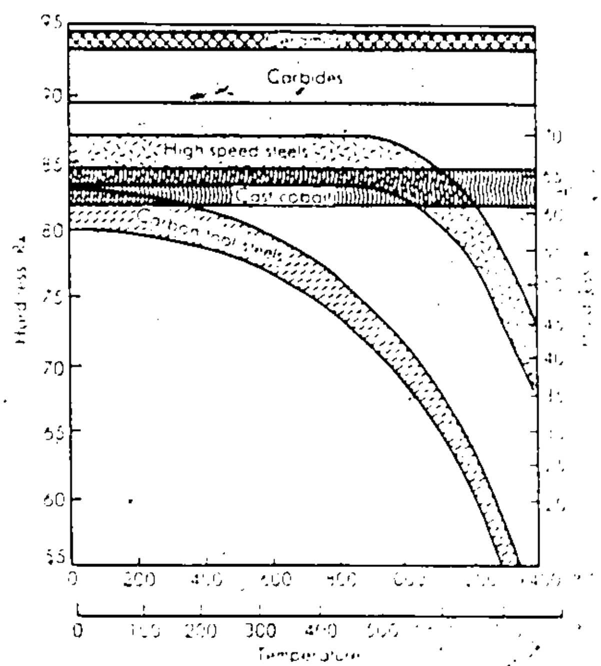


Figure 3.2 Recovery hardness for several types of cutting tool materials.

Drill Diameter (mm)	Flute Length (mm)	Overall Length (mm)	Lip Relief (°)	Web Thickness (% of drill's diameter)	Include angle at point (°)
3.18 (.125 in)	41	70	15	20	118
6.35 (0.25 in)	73	105	13	17	118

Table 3.2. Drill specifications for 3.18 mm and 6.35 mm drill-size.

Drill diameter at point. (mm)		
3.18	+0	-0.013
6.35	+0	-0.018
Shank diameter. (mm)		
3.18	+0	-0.064
6.35	+0.013	-0.076
Flute length. (mm)		
3.18	+3.2	-1.6
6.35	+3.2	-3.2
Overall length. (mm)		
3.18	+3.2	-1.6
6.35	+3.2	-3.2
Include angle at point. (°)		
$3.18 < \gamma < 6.35$	118 ± 5	
Lip height. (mm)		
3.18	0.08	
6.35	0.01	
Centrality of Web. (mm)		
3.18	0.08	
6.35	0.13	
Flute spacing. (mm)		
3.18	0.003	
6.35	0.076	

Table 3.3. Dimensional Tolerances for HSS General Purpose Twist Drill of 3.18 mm (1/8 in) and 6.35 mm (1/4 in) in diameter.

tool life obtained was considered to be appropriate for this study. Table 3.4 shows the different percentages of constitutents of the alloy steel used.

Carbon	C	:	0.38 - 0.43
Manganese	Mn	:	0.6 - 0.8
Phosphorus	P	:	0.035
Sulphur	S	:	0.04
Silicon	Si	:	0.2 - 0.35
Nickel	Ni	:	1.65 - 2.0
Chromium	Cr	:	0.7 - 0.9
Molybdenum	Mo	:	0.2 - 0.3
Brinell Hardness		:	207

Table 3.4. AISI 4340 Alloy Steel

The recommended operating speeds for the sizes of drills and workpiece material can be obtained from Table 3.5.

Material drilled	Hardness Brinell	Cutting tool material	Peripheral speed (m/min)	Feed rate (mm/rev)	Helix angle (°)	Point angle (°)
.3-.6C	175-225	HSS	15-18 (50-60 SFM)	z	25-35	118

Drill diameter (mm)	z
3.18	0.05 (0.002 in/rev.)
6.35	0.089 (0.0035 in/rev.)

Table 3.5. Recommended operating conditions for 3.18 mm and 6.35 mm drill-size.

The relationship between drill speed and spindle speed is given by the following equations,

$$V = 0.00314 * D \cdot RPM$$

or

$$RPM = (318.31 * V)/ D$$

Where,

V = drill speed. (m/min)

D = drill diameter. (mm)

RPM = spindle speed. (rev/min)

3.4. Experimental Procodure.

Before the start of any drilling operation, the drill was cleaned in ord to get rid of any packaging grease as dry drilling was desired. The drill was fitted to the chuck which was mounted in a tool post. The alignment between the tip of the drill and the center of the face of the specimen was done so as not to introduce any extraneous vibration into the process. Figure 3.3 shows the experimental setup before any drilling operation. The workpieces were cut from a bar stock into lengths of 50.8 and 25.4 mm depending on the drill's size used. They were also centered-drilled in order to eliminate the wander action at the drill-point when the drill first make contact with the workpiece.

After the initial preparation of the drill, workpiece, and the proper set-up of the lathe, the following steps were taken to perform the drilling operation:

1). The lathe was turned on.

2). The tape-recorder was turned on and the necessary comments regarding the drill conditions were recorded on

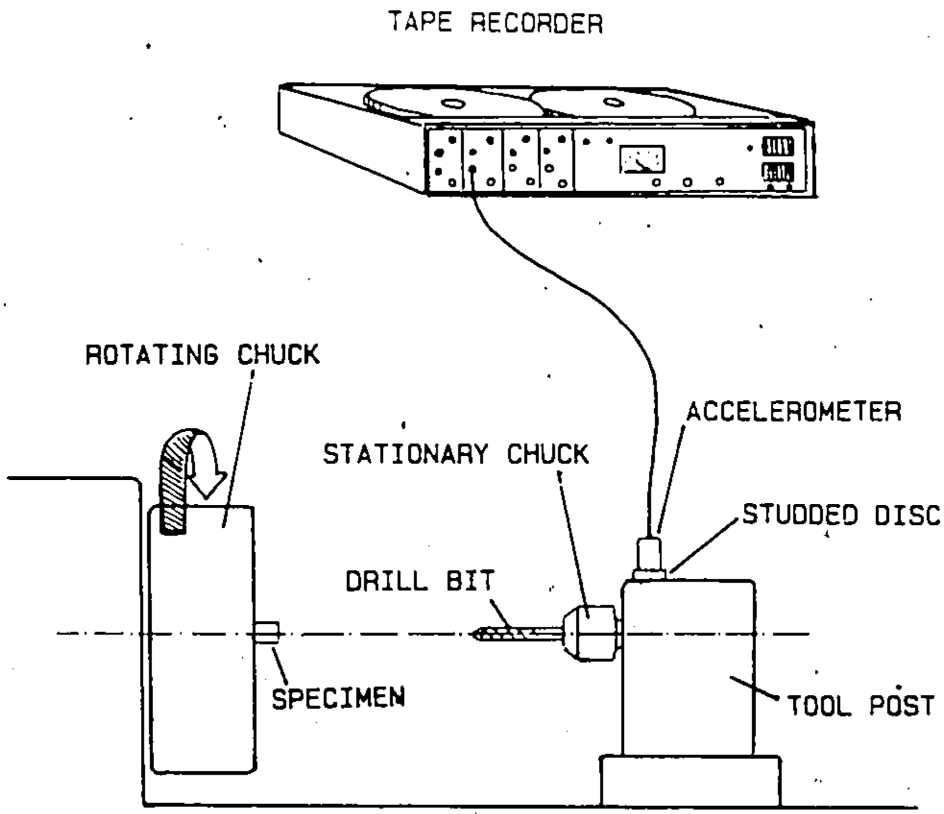


Figure 3.3 Experimental set-up.

tape.

3). Feed was engaged to start drilling only when the constant or steady-state tape speed conditon was attained.

4). The drilling operation was stopped after the depth of three times the drill diameter was reached.

5). The tape recorder was turned off.

6). The drill was removed from the chuck and placed in a drill-holder for tip wear measurement. See Figure 3.4.

7). Drill was placed back into the chuck at the same locetion and orientation as before in order to establish consistency in the experiment.

8). Proceed to step (2) until failure occurs, namely, when the drill broke or became excessively worn.

The tip wear measurement was performed on a travelling microscope which has a magnification of 2ØX and an accuracy of measurement down to the nearest Ø.Ø1 mm. Tip wear is defined in accordance with normal industrial practice as the length of worn portion of the drill at the drill point along the cutting edges. Figure 3.5 shows this distance as the drill diameter minus the distance "d".

All information about the operating conditions, tip wear measurements and accessories for the drilling operation were recorded on standard drill data sheets for ease of future analysis and reference. A sample of these data sheets are shown in Figures 3.6(a), 3.6(b).

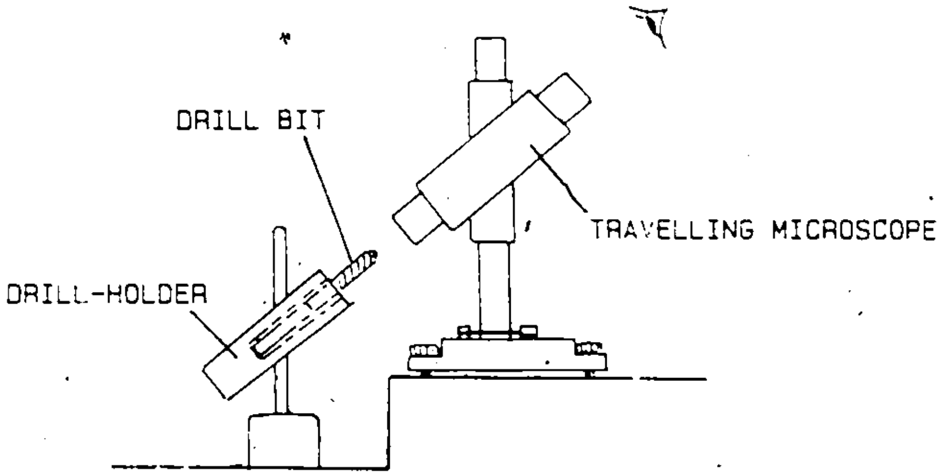
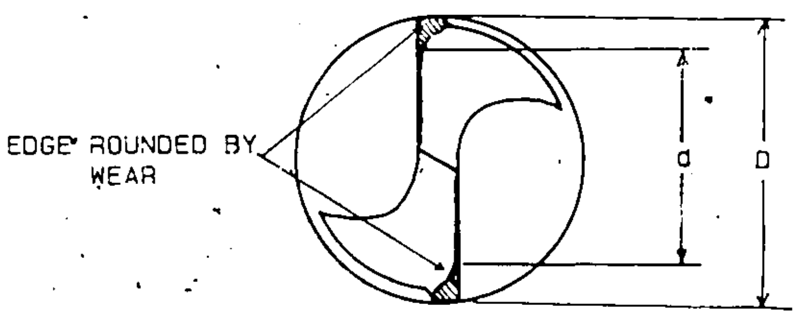


Figure 3.4 Schematic diagram for tip wear measurement.



Tip wear = D - d

Figure 3.5 Tip wear measurement.

DRILLING DATA	
DATA RECORDED: 20/8/87	TAPE #: 100
DRILL #: D1	DRILL SIZE: 6.35 mm
DRILL MANU'FTR: OSBORNE-MUSHET	
MACHINE TOOL: OKUMA LS	
SPINDLE SPEED: 1100 RPM	FEED RATE(in/rev): 0.0052
ACCELEROMETER: B&K 4384	GAIN: -
TAPE RECORDER: B&K 7005	TAPE SPEED: 381 mm/s
CHANNEL 1: Signals	GAIN/ATTN LEVEL: gain 1
CHANNEL 2: Comments	GAIN/ATTN LEVEL: -
SPECIMEN MATL: AISI 4340	
TOTAL # OF HOLES: 23	
HOLE #'S EXCEEDING RANGE: -	
COMMENTS:	
-Good drilling.	

Table 3.6(a) Drilling data.

TIP WEAR MEASUREMENT

HOLE #	WEAR(mm)	HOLE #	WEAR(mm)
1	0.18	24	1.42
2	0.41	26	2.01
3	0.46	.	.
.	.	.	.
.	.		
.	.	.	.
.	.	34	2.79
20	0.99		
22	1.09		

Table 3.6(b) Tip wear data.

Chapter IV

ANALYSIS OF DATA

In this chapter, the analysis procedures which were developed to extract the required information from the analog vibration signal stored on the magnetic tape are described. The following subjects are included in the discussion:

1). Classification of the vibration signals from the drilling process.

2). Description of equipment required in the data processing.

3). Data preparation.

4). The detail data processing procedures.

5). The use of computer programs in this data analysis process.

4.1. Classification of the vibration signals.

Generally, in the first step of the analysis, it must be established if the signal is deterministic or nondeterministic in nature. Deterministic data are those that can be described by some explicit mathemetical function, hence they are usually easier to comprehend and analyze. As shown in Figure 4.1 and Figure 4.2, the particular sets of data can be easily correlated by mathematical functions of straight line and periodic sine wave respectively. On the other hand, non-deterministic data or random data represent a random physical phenomenon which cannot be described by an explicit mathematical relationship because each observation is unique. It is to this latter category that

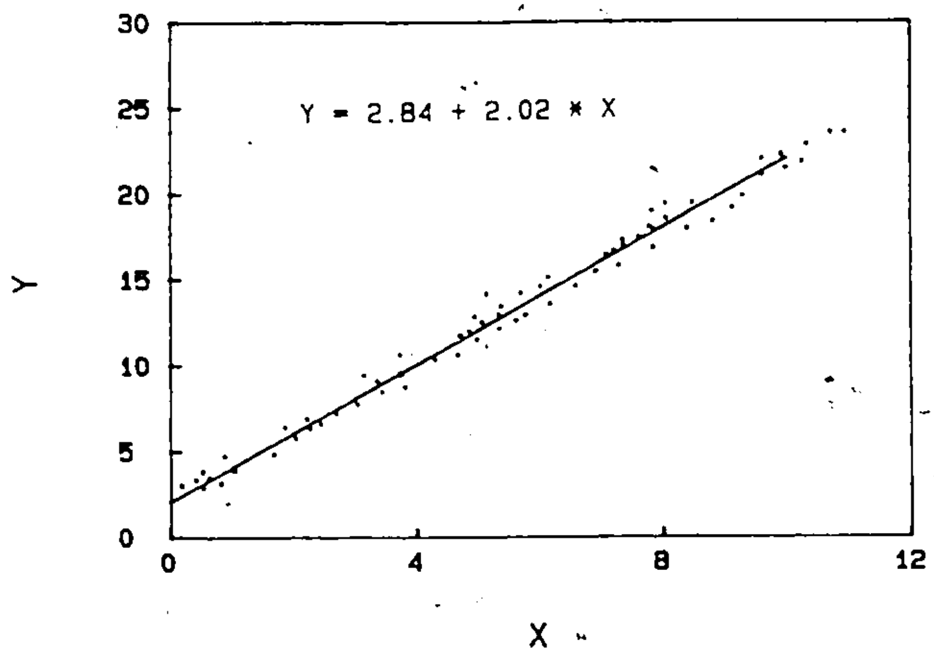


Figure 4.1 Deterministic data - straight line correlation.

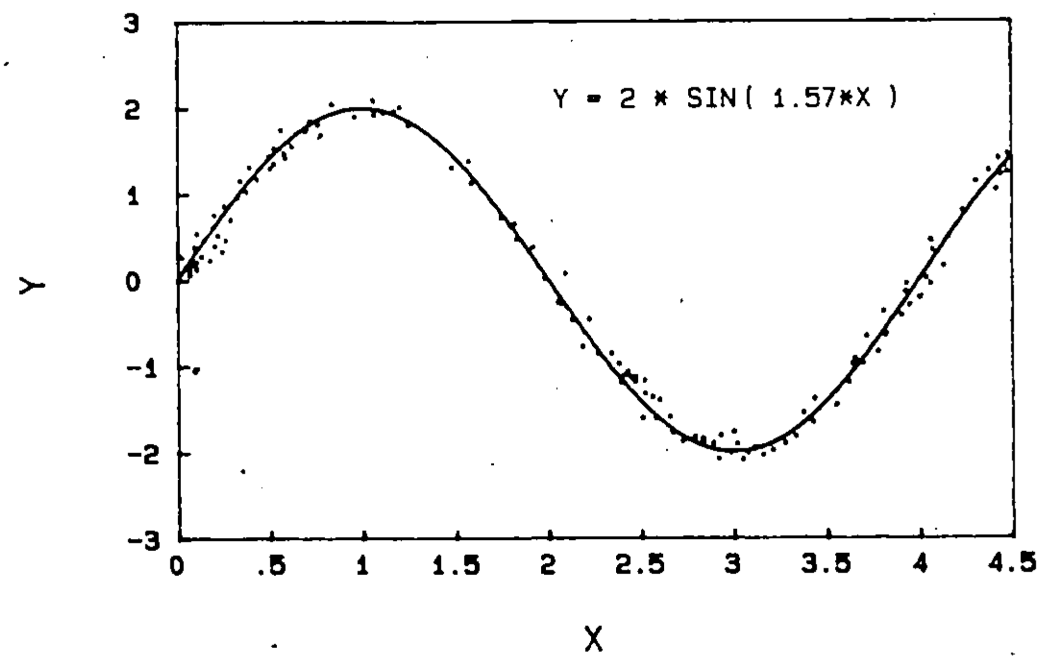


Figure 4.2 Deterministic data - sine function correlation.

vibration signals from the drilling process belong. Certainly, the vibration signal obtained from the drilling process, as shown in Figure 4.3, would be very difficult to be described by any mathematical function. Futhermore, the signal is unique and is strongly related to the type and degree of wear occuring at the cutting edges.

Knowing the fact that vibration signals are non deterministic, it was decided to describe the characteristic of the signals by some sort of statistical functions, such as: central tendency, spread/dispersion, asymmetry, etc. This statistical analysis was performed in the time domain.

The following were the statistical parameters chosen for study:

1). Mean value.

2). Standard deviation.

3). Skew.

4). Kurtosis.

5). RMS of the distribution.

4.2. Equipment selection.

Essentially, five pieces of equipment were selected in this data analysing process, as shown in Figure 4.4. There were the tape recorder, B&K 7005 or Nagra IV-JS, for the signal playback, B&K wideband filter (0-10 kHz), AI13 A/D converter (analog to digital signal conversion), Apple II plus computer for performing the data analysis, and the Prowler Digital Oscillo scope for providing visual aid to the signal being analysed.

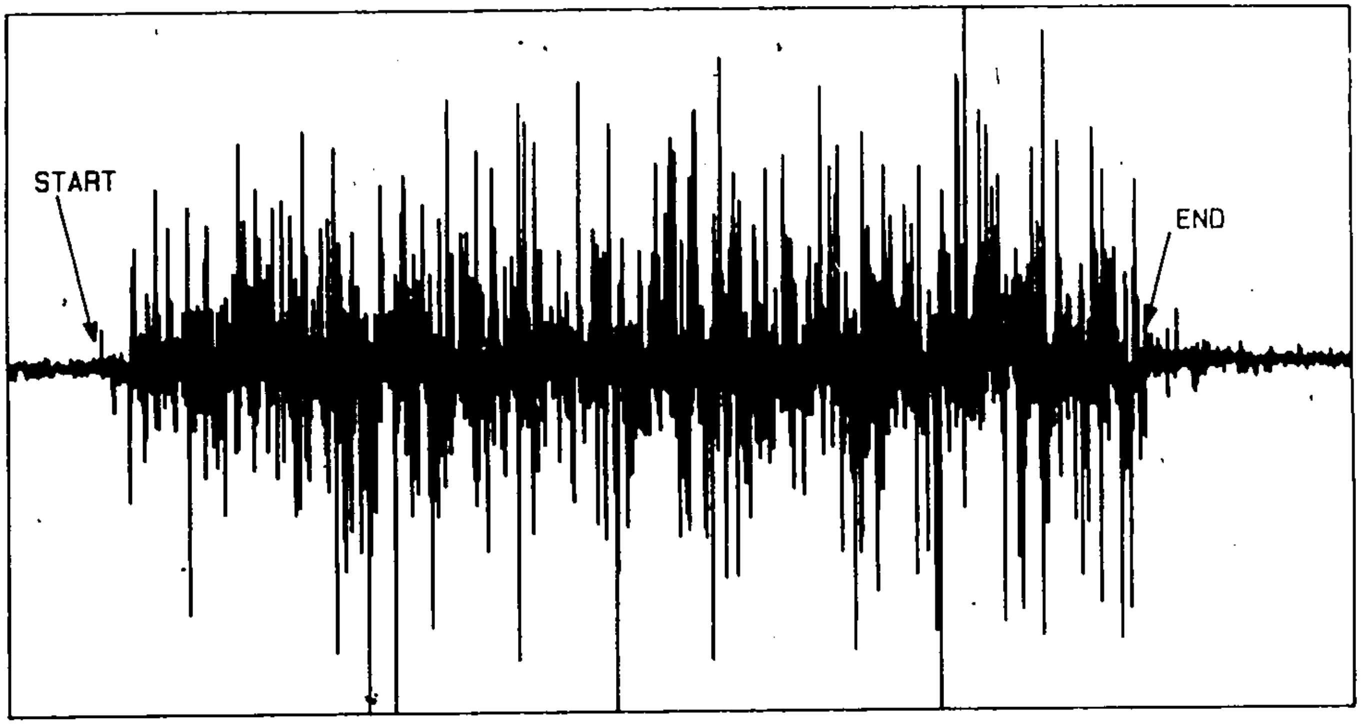


Figure 4.3 Vibration data from the drilling process.

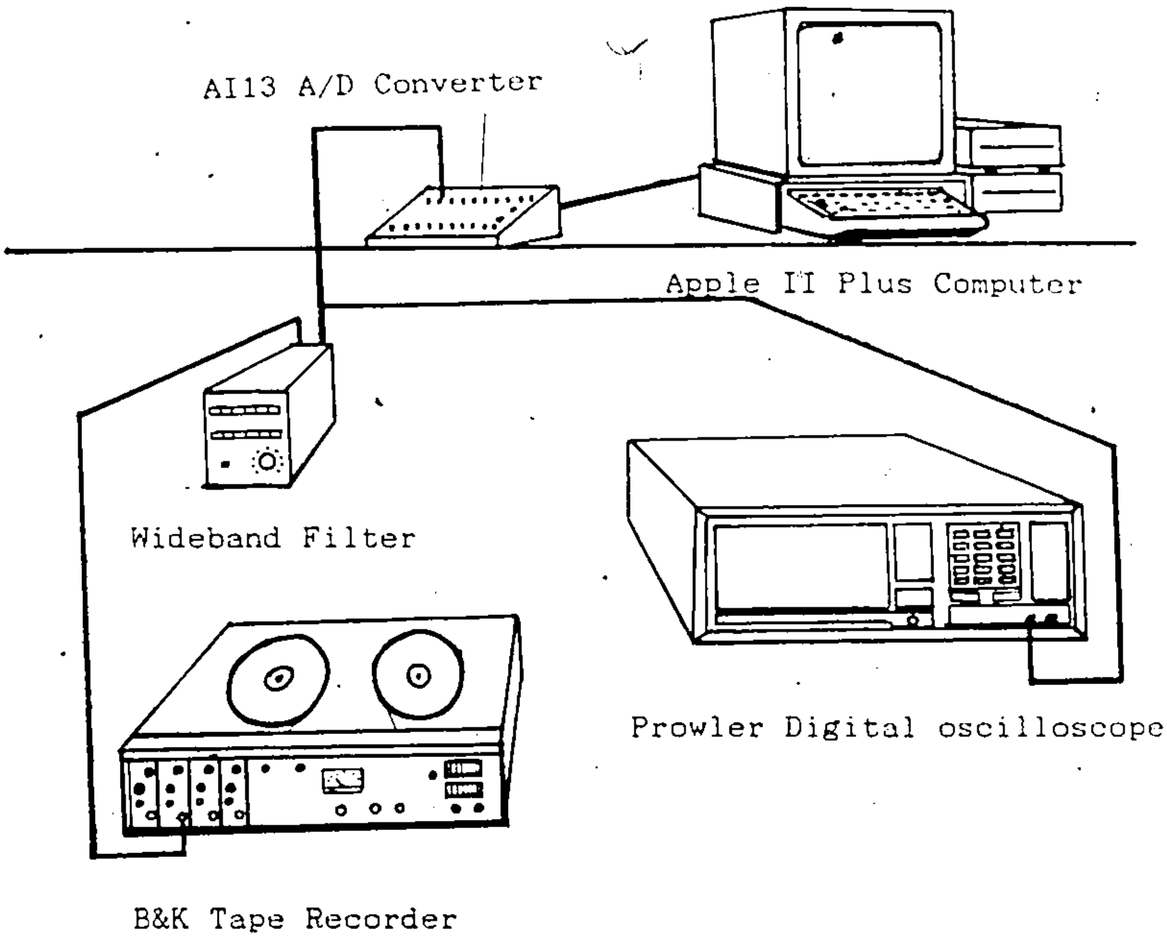


Figure 4.4 Schematic diagram for the data analysis.

The very first step in the data processing involved the playback of the stored vibration signals, using the same recorder on which the tape was recorded. This helps to minimize any time base errors in signal reproduction which could be due to variation in recording speed between recorders, and/or skew (variation in angle at which the tape passes over the head). Other errors introduced by the tape itself such as dimensional changes of the tape due to temperature, humidity, and tension should also be noted.

The signals were filtered by passing them through a B&K 2638 wideband filter. The passband of the filter used was from 0.1 to 10 kHz. The passband frequencies were chosen mainly because of the fact that the predominant drill vibration in this range was shown to be sensitive to drill wear [53,64]. According to Xistris, Boast and Sankar [78], an analysis system capable of processing signals with the frequency content up to 10 kHz is sufficient for this type of machinery vibration monitoring.

The filtered analog signals were digitized using AI13 A/D converter which has a sampling rate of 20 kHz. The AI13 A/D converter is a high performance 12-bit data acquisition system for the Apple II computer. It plugs directly into any one of the Apple expansion slots and gives the Apple the ability to make precision voltage measurements. It can select one of the 16 input channels, scale the input according to any one of the 8 full-scale range, and return the result in less than 20 microseconds, represented by a number between 0 and 4095. The conversion process is done by some successive approximation steps, a binary search for the value of the unknown input signal. A more detailed description of this piece of equipment is given in Appendix B. The digitized data were stored in the memory of the Apple II plus computer and were then analysed by programs written in Applesoft Basic.

The sole function of the prowler digital oscilloscope was to provide visual presentation of signals being analysed. This piece of equipment is manufactured by Norland corporation and has three functional characteristics, namely as an oscilloscope capable of acquiring signals from dc to 20 MHz, powerful analysis instrument with a variety of pre-programmed operations, and it is programmable.

4.3. Data preparation.

In most cases, signal/raw data has to be "prepared" before any detailed analysis can be performed. In this study, as the analysis was performed digitally, the preparation steps can be grouped as follow:

1). Data editing.

2). Digitization.

4.3.1. Data Editing.

Data editing is the process involving the playing-back of vibration signals on the tape recorder and displaying them on the Prowler digital oscilloscope. By visually inspecting the signals, it was easy to determine if they were recorded properly in terms of signal to noise ratio, and whether enough gain or attenuation had been introduced prior to recording. Hence, it is designed mainly to detect and eliminate spurious and/or degraded data signals which might have resulted from acquisition and recording problems such as those mentioned above i.e excessive noise, signal dropout, etc. Another valuable piece of information can also be extracted through this process, namely the highest amplitude range of the signal, which is very useful in the digitization process.

4.3.2. Digitization.

It consists of two distinct operations: sampling, and quantization. In this study, these operations were performed by the AI13 A/D converter. The process consists of 6 microseconds of sampling and hold, and 13 microseconds of conversion time (quantization). This operation is very important in all analysis which involves the data conversion from analog to digital, hence special attention should be paid to the theory, processing, and potential sources of error encountered.

4.3.2.1. Sampling.

Sampling is the process of defining the instantaneous points of some continuous time record. Figure 4.5

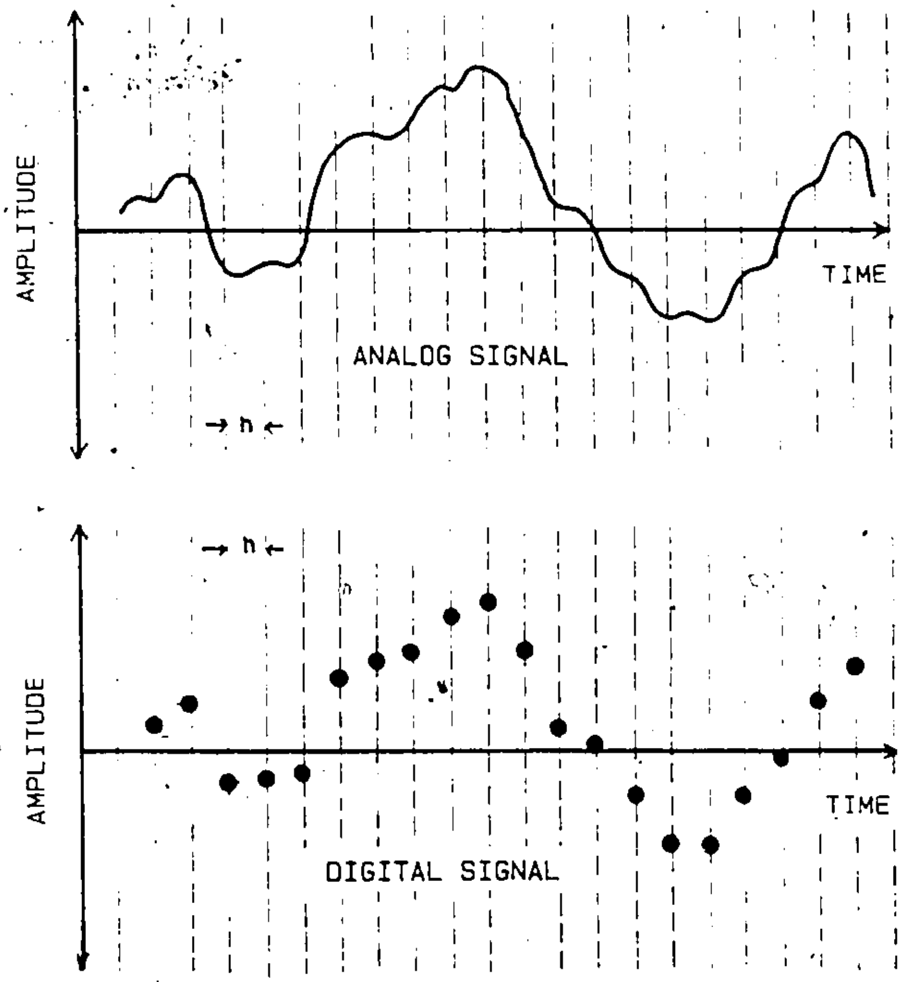


Figure 4.5 Sampling process of a continuous time record.

shows the process of sampling of a continuous record. As can be seen, sampling is usually performed at equally spaced intervals "h". Determination of this sampling interval, "h" does involve some theoretical justification. Too small a sample interval will result in highly redundant data, and thus an unnecessary increase in the labour and cost of calculations. On the other hand, sampling at points which are too far apart will lead to confusion between the low and high frequency components in the original data. The latter problem is called aliasing. From theory, in order to eliminate the problem of aliasing, the sampling rate required for A/D should be at least 2.56 time the highest cutoff frequency of the original data.

Unfortunately, due to the limited memory space in the Apple II plus computer (64 k), one additional quantity has to be introduced in this sampling process, namely sampling interval delay (Ds). As the name implies, sampling interval delay will decrease the sampling range of points of the orginal data. It can be incorporated into this sampling operation by using Figure 4.6, after knowing the number of digitized data desired and the time required in drilling a hole.

4.3.2.2. Quantization.

It is a process of representing the magnitude of each data sample by some number. Since only a fixed number of levels are available for approximating the infinite number of levels in the continuous data, a choice between two consecutive values will be required. The error occuring in this data representation is called quantization error and in most cases it

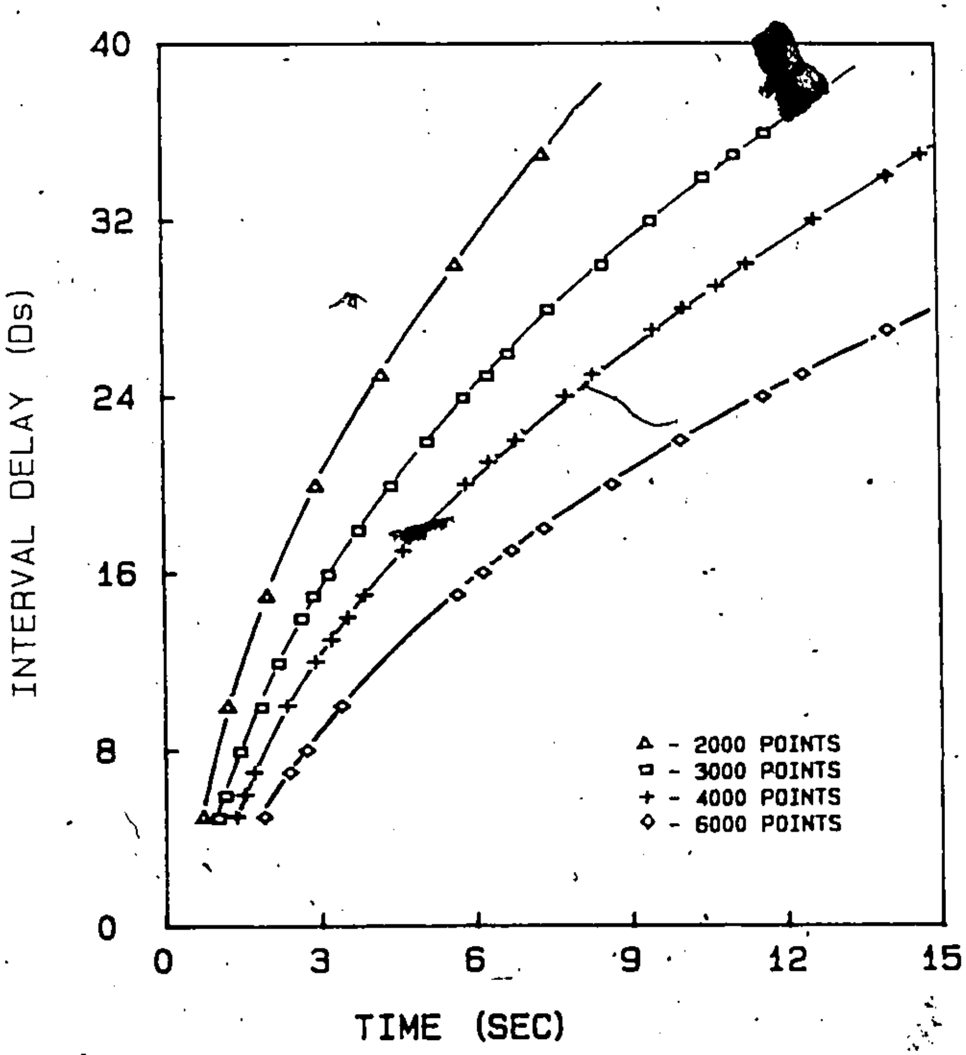


Figure 4.6 Plot of interval delay versus time at different number of digitized data.

is unimportant relative to other sources of error in the data acquisition and processing procedures. Using the AI13 A/D converter, the range of numbers representing the data sampled is between Ø to 4Ø95. To minimize this quantization error, care should be exercised to assure that the amplitude range of the continuous data is set to occupy as much of the available quantizing range as possible. As can be seen, the determination of the highest amplitude range of the analog signal during the process of data editing is important.

Conversion of the digitized data back to physical units is needed in most cases of data analysis. Knowing that, most digitizing procedures produce information, in units that are related linearly to the true physical units, a common technique is to digitize a reference or calibration signal at the same time the data are digitized. It is then possible to determine the relationship between digitized units and physical units directly. In this study, a calibration signal of 159 Hz with magnitude of 1 g (gravitational unit), has been recorded on the start of every new tape, solely to serve the above purpose in data processing.

4.4. Data analysing procedures.

With the digitized data residing in the computer memory, two operations can be performed on the data, namely store the raw data onto the diskette and/or go through a 'grouping' operation. Generally speaking, those two operations are equally time consuming. Figure 4.7 shows just how [illegible] it would take to store or group different number of digitized data.

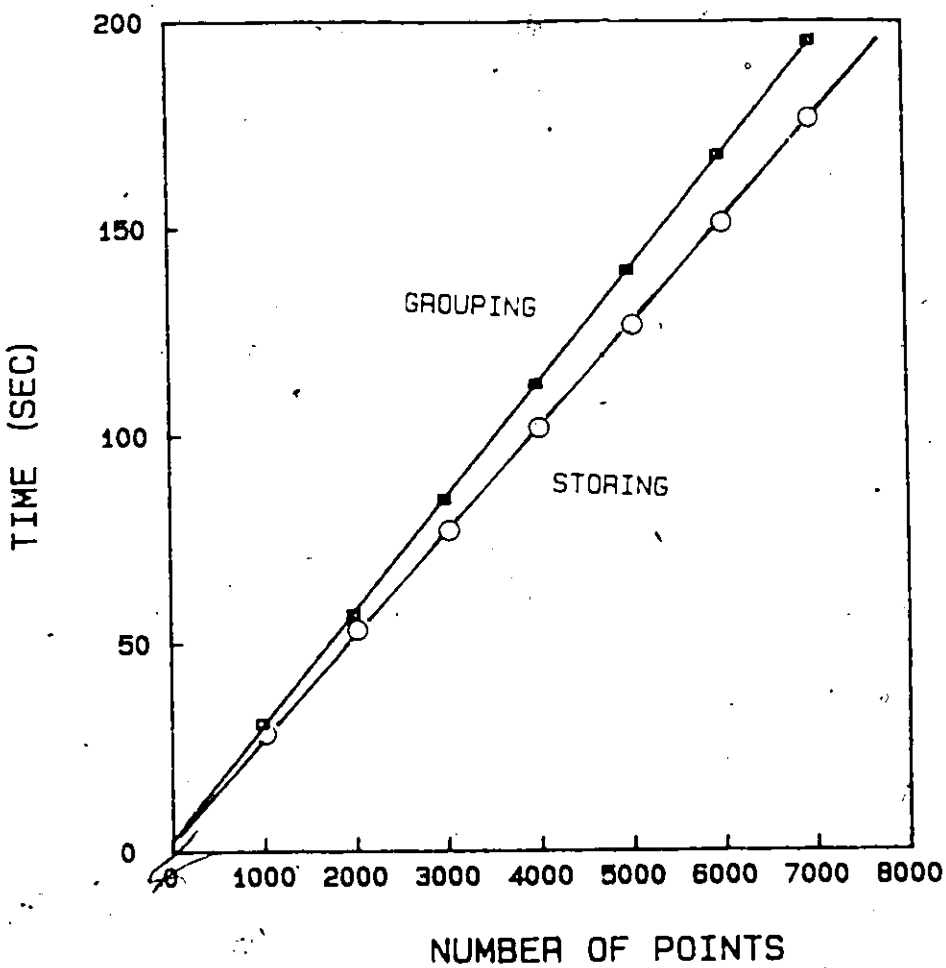


Figure 4.7 Time required to store and group different number of digitized data.

If the data are in the order in which they occur, they are said to be in the form of ungrouped data/raw data. Grouping of data in classes of equal interval/width can be proven to be more advantageous if the total number of samples is greater than 40 [50]. Arrangement of samples in class interval, with the class frequencies tallied, produces a grouped frequency distribution of amplitude or statistical frequency distribution. The noted advantages of grouping over ungrouped data are: faster statistical computation and the frequency of occurrence or clustering at different class intervals can be easily determined from the distribution. The choice of the number of classes in this grouping operation has been simulated and obtained by a computer program.

Figure 4.8 shows the computation time needed in calculating the five statistical parameters, previously mentioned, on a grouped as compared to ungrouped raw data. Clearly, the grouped case has a significant reduction in the computation time, more so as the sample taken increase in size. In this project, all statistical analyses were started with grouping of the raw data. Figure 4.9 shows diagrammatically the process of digitizing the analog signal and expressing the digitized data in the form of a statistical frequency distribution (grouping).

Information about the characteristics of the statistical frequency distribution can be described through the measure of its central tendency, dispersion, asymmetry, and peakedness.

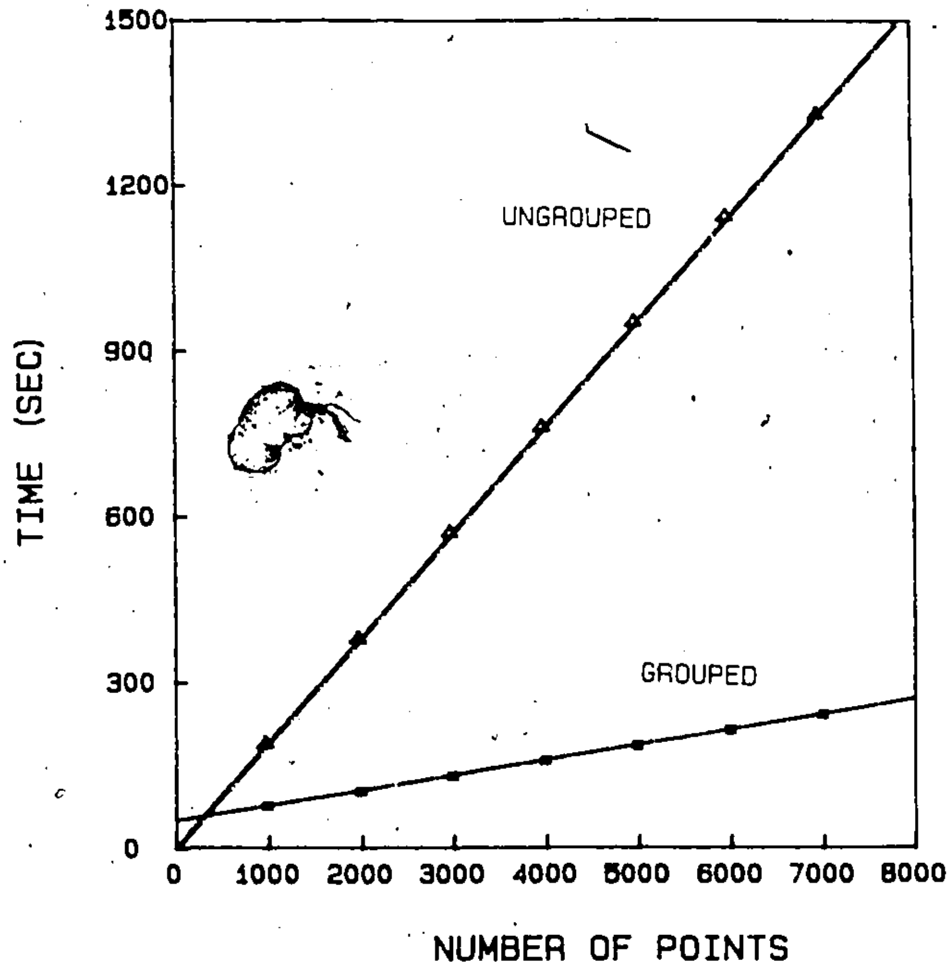


Figure 4.8 Computation time required to calculate those statistical parameters of grouped data as compared to ungrouped case.

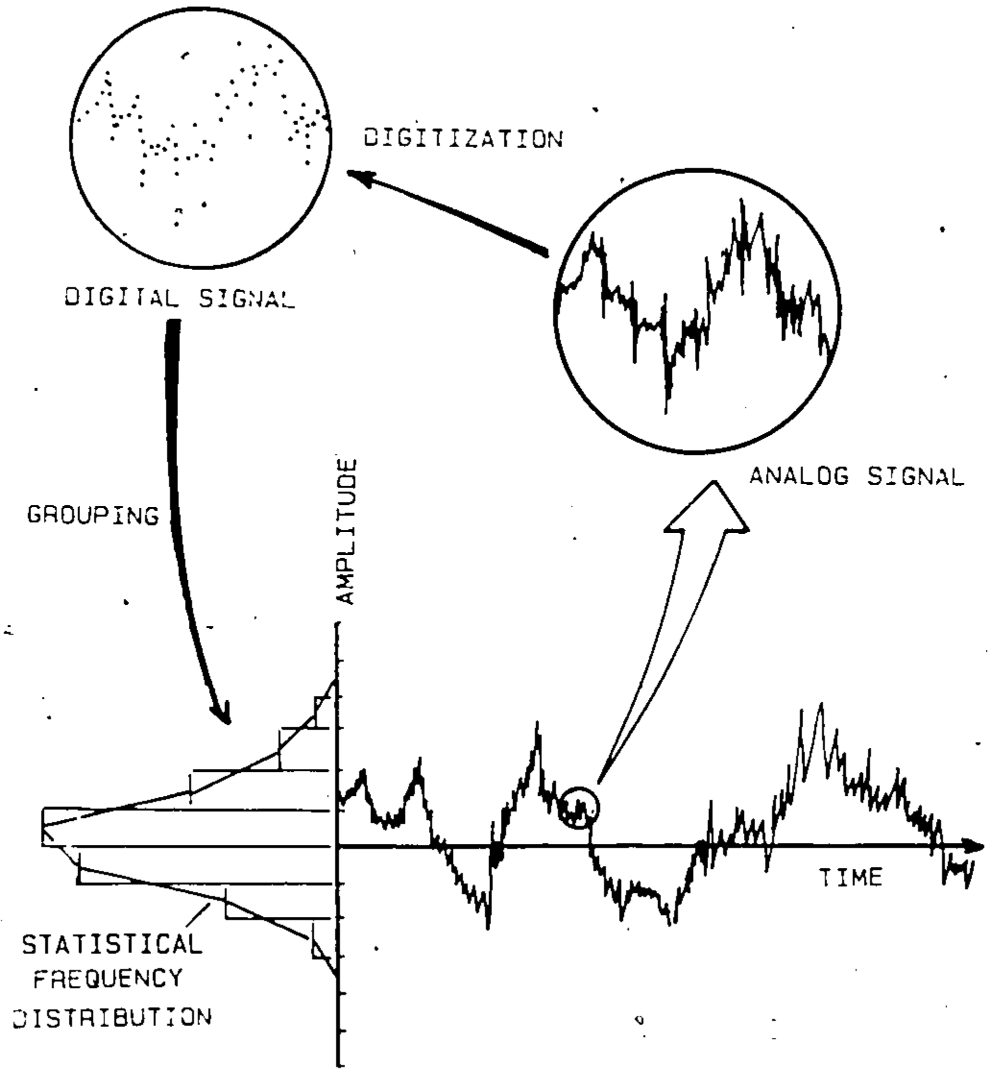


Figure 4.9 The schematic diagram of digitization, and grouping process.

In order to present information about the distribution in a clear and consise form, some sort of numerical measure of those characteristics have to be developed.

Suppose in a statistical frequency distribution, there are N different values $X_1, X_2, X_3, \ldots X_N$ which occur respectively $F_1, F_2, F_3, \ldots F_N$ times; as shown in Figure 4.10. The r^{th} moment of the distribution about the weighted mean $\bar{X}$ can be defined by

$$M_r = \frac{\sum_{i=1}^{N} F_i * (X_i - \bar{X})^r}{\sum_{i=1}^{N} F_i} \qquad \text{———} \quad 4.1$$

$$\bar{X} = \frac{\sum_{i=1}^{N} F_i * X_i}{\sum_{i=1}^{N} F_i} \qquad \text{———} \quad 4.2$$

4.4.1. Measure of central tendency.

Observations generally have the tendency to center or group themselves around a central value. The measure that can be used to describe this characteristic is the mean $\bar{X}$ defined by equation 4.2. The mean is also known as the first moment about the origin.

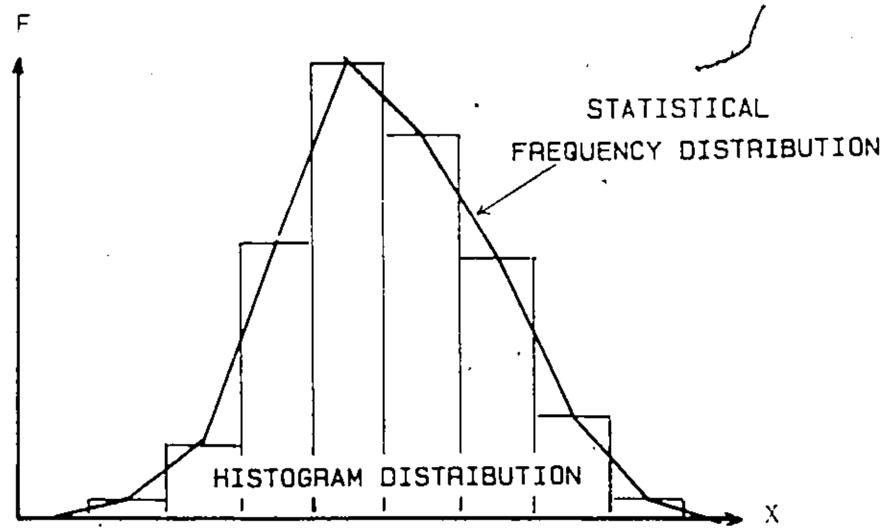


Figure 4.10 Typical statistical frequency distribution.

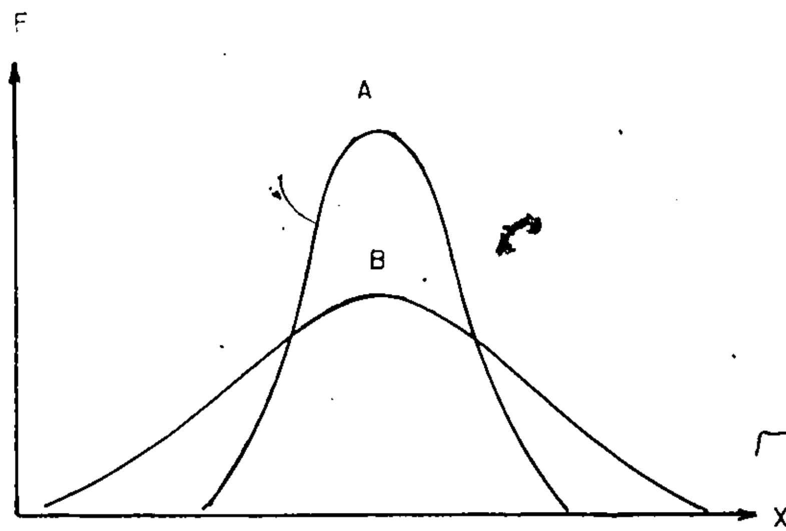


Figure 4.11 Distributions with different degree of dispersion.

4.4.2. Measure of dispersion.

Dispersion can be defined as the degree of clusterness of observations about the mean. As shown in Figure 4.11 clearly, both distributions exhibit essentially the same central tendency, but distribution A does show less variation about the mean than distribution B.

The measure that can be used to show this charateristic of the distribution is the second moment about the mean, defined by equation 4.1, with r=2, called the variance. As the dimension of variance is in square units, which is sometimes awkward to interpret, another measure, called standard deviation, i.e the positive square root of the variance, is used. It is defined by

$$\sigma = (M_2)^{0.5} \qquad \text{4.3}$$

4.4.3. Measure of asymmetry.

Consider the three distributions as shown in Figure 4.12. Distribution A is symmetrical, whereas distribution B and C show lack of symmetry. So skew, which is a normalized third order central moment, can be used as a measure of the amount and direction of asymmetry. It is defined by equation 4.4.

$$\mu_3 = \frac{M_3}{(M_2)^{3/2}} \qquad \text{4.4}$$

The numerical value of μ_3 reflects the extent of the asymmetry or skewness of the distribution, with the sign of μ_3 indicating the direction of the asymmetry. From Figure 4.12, distribution A has the value of μ_3 equal Ø where as distribution B and C have the sign of μ_3 to be positive and negative respectively.

4.4.4. Measure of peakedness.

As shown in Figure 4.13, all three distributions exhibit more or less the same central tendency, dispersion, and the same symmetry, but different degree of peakedness. Kurtosis, the fourth order normalized central moment is the measure that is needed to describe this characteristic of the distribution and is defined as follow.

$$\mu_4 = \frac{M_4}{(M_2)^2} \qquad \text{———————} \quad 4.5$$

This measure, however, is very sensitive to the tails of the distribution. In other word, it is dominated by the deviations from the mean to the fourth order.

From Figure 4.13, distribution A has more or less a normal distribution, hence the corresponding kurtosis value will be close to 3. Distribution B has a larger deviation than A, hence its kurtosis will have a value greater than 3. Distribution C has the largest deviation among the three, therefore its kurtosis will be the largest.

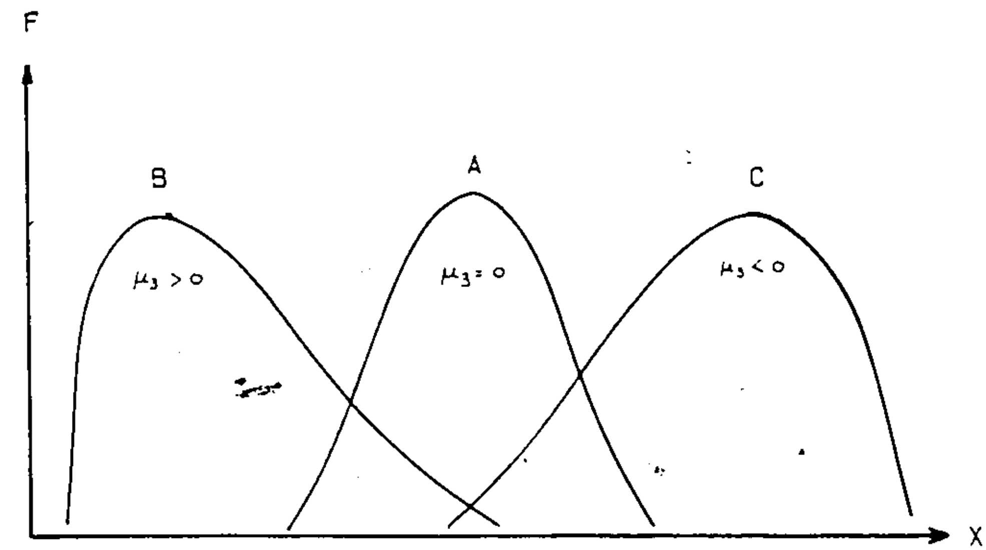


Figure 4.12 Distributions with different degree of asymmetry.

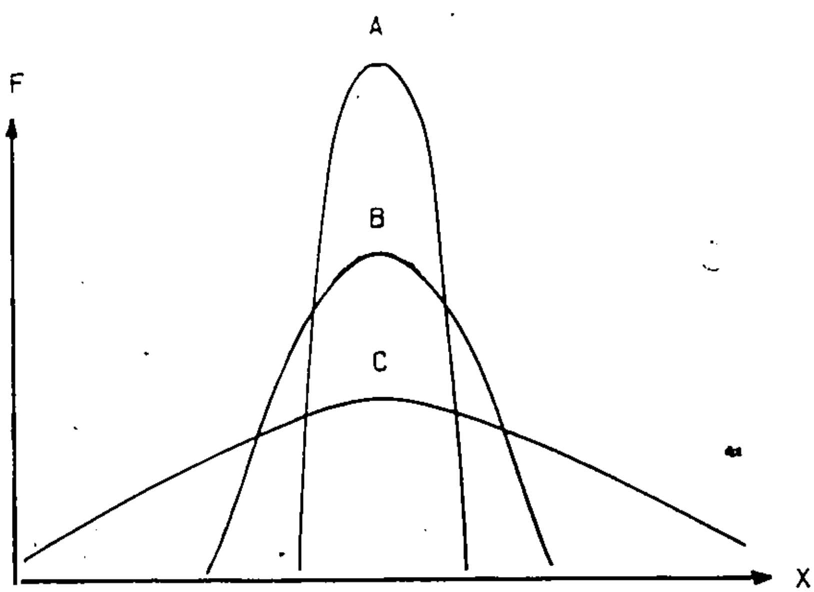


Figure 4.13 Distributions with different degree of peakedness.

Another measure of the peakedness of the distribution, which is not sensitive to the spread of the tails of the distribution, is the RMS of the distribution defined by the following formula.

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} F_i^{\,2}}{N}} \qquad \text{———} \quad 4.6$$

4.5. Computer program.

Under the situation where the analysing procedure is definable, repetitive and involving large quantity of data, it is justifiable to use a computer for processing. In this study, three major Applesoft basic programs were written for data processing. Figure 4.14 shows the schematic diagram of the computer-network used.

4.5.1. Data acquisition program.

The data is acquired from the tape recorder through the use of the AI13 A/D converter. As storing the digitized data onto the diskette and 'grouping' take more or less the same amount of time, but with a significant increase in storage space needed on the diskette, the following options were included in this program.

1). Acquiring data by specifying the number of digitized data desired (N), the amount of sample interval delay needed (D),

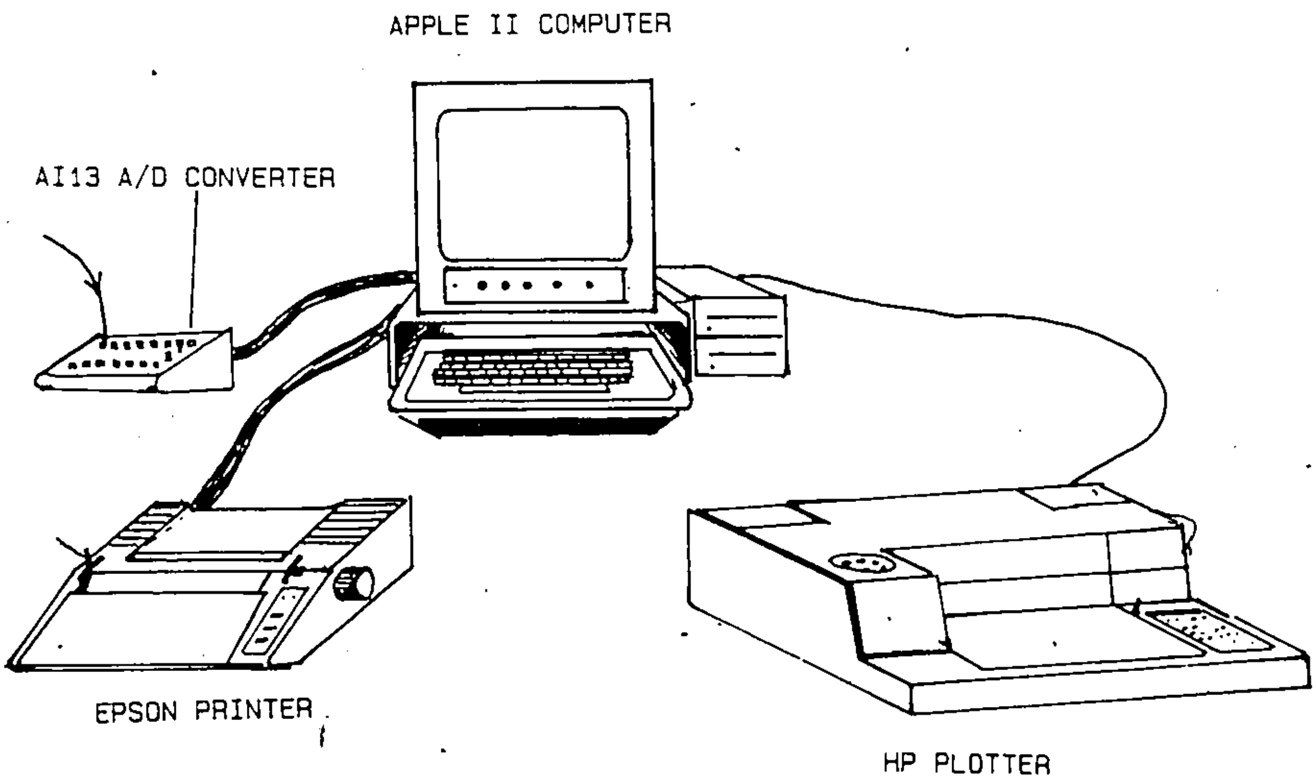


Figure 4.14 Schematic diagram of the computer-network employed.

and the selection of the input signal level (GC).

2). Option of storing the digitized data onto the diskette and/or proceeding to the grouping operation.

3). Acquire another signal.

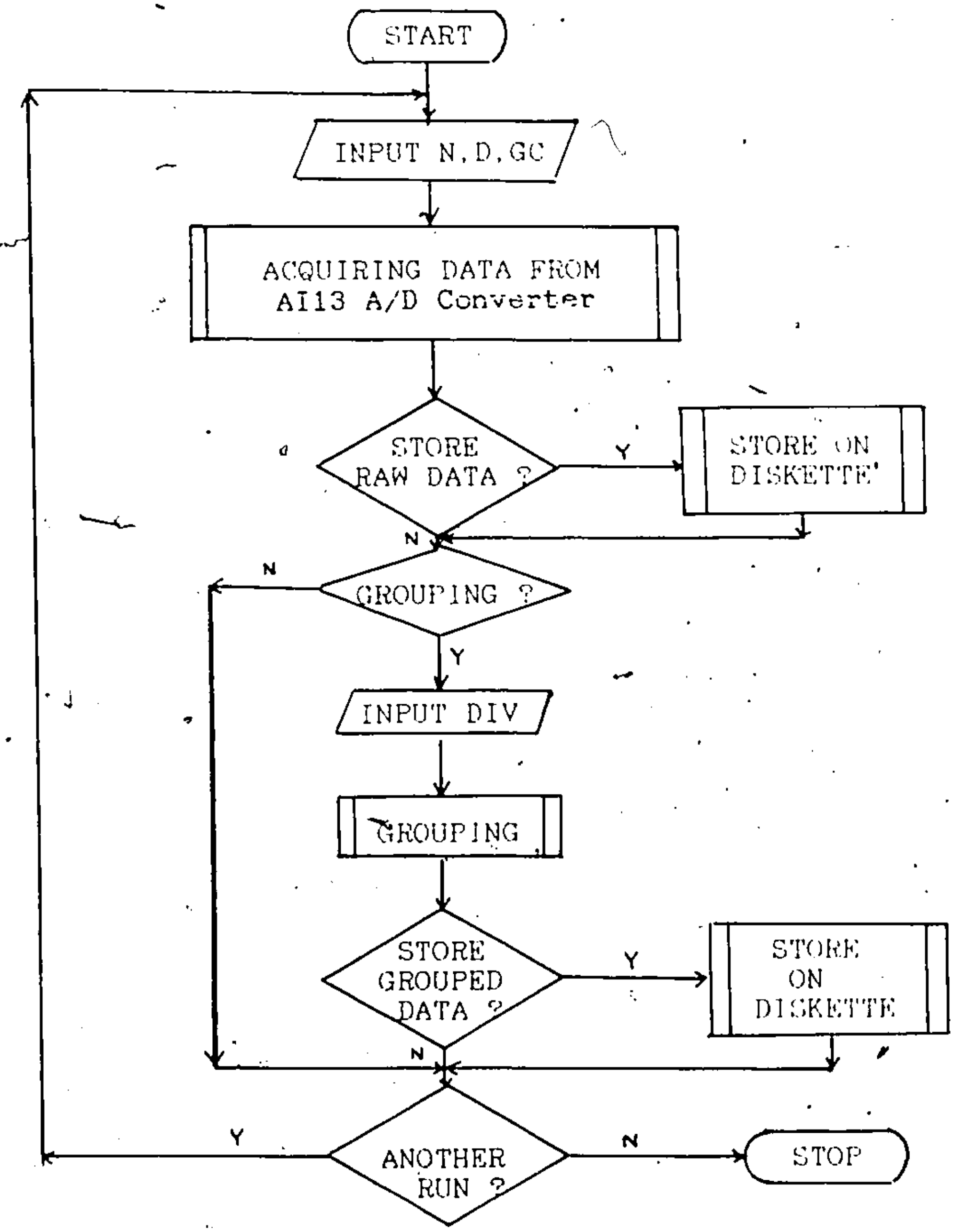
Figure 4.15 shows the top-level flow-chart of this data acquisition program. The program listing is included in Appendix C.

4.5.2. Statistical analysis program.

This is the program that calculates the five chosen statistical parameters. The analysis can be performed either on the grouped or ungrouped data. In addition, routines such as grouping, storing the statistical data (grouped) and statistical results onto the diskette, printing of raw data, statistical data and results either on the screen or the printer, are also included. The top-level flow-chart of this program is shown in Figure 4.16 and the program listing is also included in Appendix C.

4.5.3. Plotting and curve-fitting program.

This program plays a very important role in the data-analysis network as it is used not only at the early stages of the analysis for visual inspection of relationship between variables, but also for the presentation of final results at the final stage of the analysis. Presentation of data/results in graphic form has noted advantages over other form of presentation because it can be developed quickly and easily, outliers can be



N = Number of digitized data desired.
D = Sample interval delay.
GC = Gain-code (Range of the input signal).
DIV = Number of divisions/classes.

Figure 4.15 Top-level flow chart for the data acquisition program.

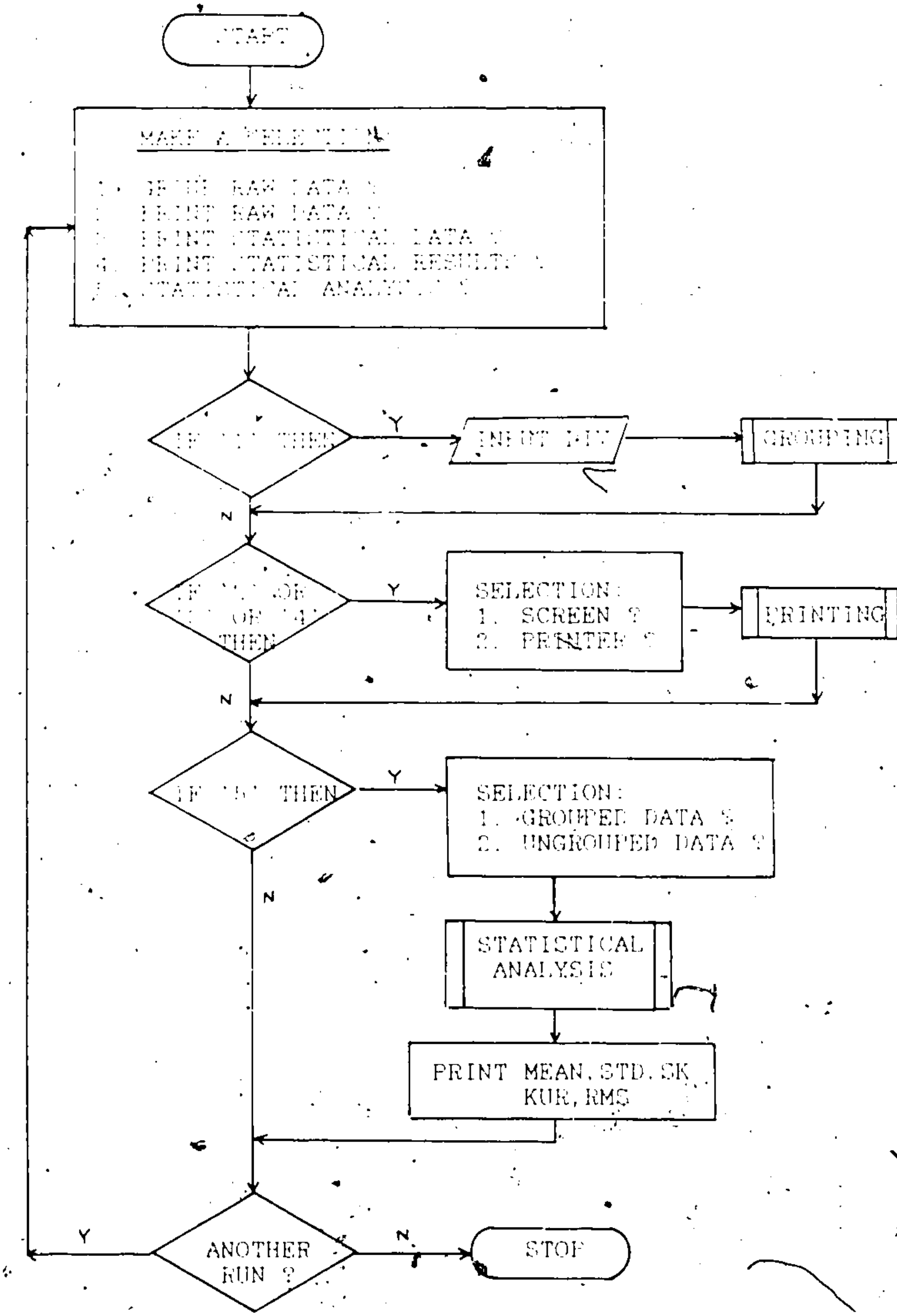


Figure 4.16 Top-level flow chart for the statistical analysis program.

identified easily and eliminated, and often a large amount of data san be presented in a compact form. The options included in this plotting and curve-fit program were:

1). Location of data/results.

2). Device used for plotting namely; screen, printer, or plotter.

3). Elimination of outliers through the data-manipulation routine.

4). Curve-fitting the data/results.

The top-level flow-chart of the program can be seen in Figure 4.17 and the program listing is available in Appendix C.

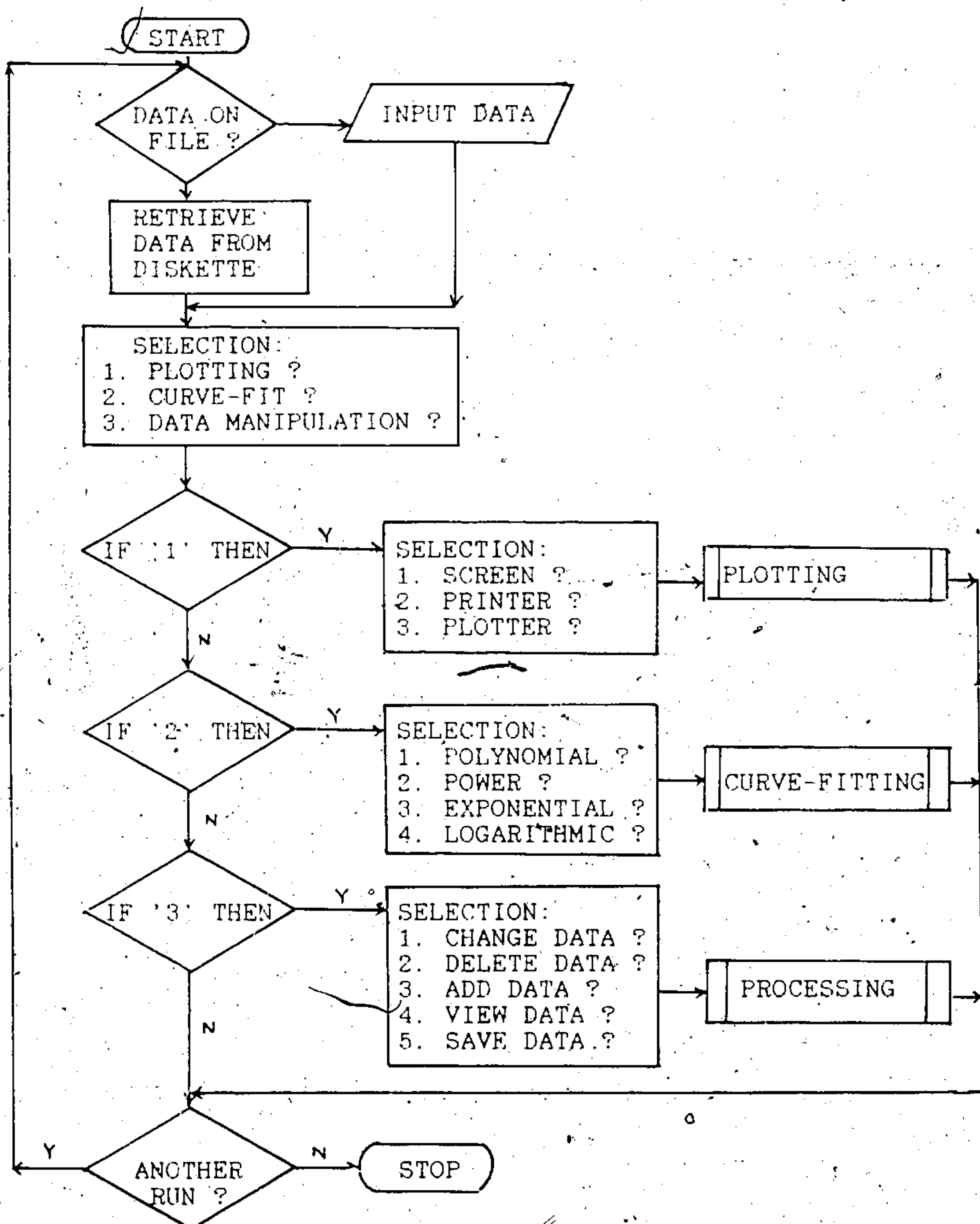


Figure 4.17 Top-level flow chart for the plotting and curve-fitting program.

Chapter V

DISCUSSION OF RESULTS

The results that are presented in this chapter correspond to the fifteen 3.18 mm diameter drill bits which were used for this investigation with additional results obtained from 6.35 mm drills. The analysing procedures which were described in Chapter IV were used.

Table 5.1 and Table 5.2, give basic data of all these drills, with additional information on operating conditions; drilling machine, workpiece material, vibration transducers, tape recorders and the tool-life observed in terms of the total number of holes drilled. All listing of the statistical results are included in Appendix A.

5.1. Drill-life distribution.

As can be seen from Table 5.1, there is quite a scatter in the drill-life distribution for drills operated near the recommended conditions for the 3.18 mm diameter, namely, an operating speed of 1700 RPM and a feed rate of 0.002 in/Rev. Assuming that all drills in Table 5.1 are operated under similar conditions, then the observed mean drill-life is 26 holes with a standard deviation of 16 holes.

A similar analogy can also be drawn from Table 5.2, for the 6.35 mm drill-size, namely the observed mean drill-life is 25 holes with a standard deviation of 6 holes.

The coefficient of variation for this type of machining

Drill Diameter : 3.18 mm (1/8 in)
Manufacturer : Cleveland

Drill #	Speed (RPM)	Feed rate (in/rev)	Machine Tool	Acc. type	Tape Recorder	Workpiece Material	Total # of Hole	Vib. signal Gain
A1	2000	0.024	Harrison	B&K 4384	B&K 7005	4340	55	3.16
A2	"	"	M 400	"	"	"	11	"
A3	"	"	"	"	"	"	44	"
A4	"	"	"	"	"	"	28	"
B1	1860	"	Colchester	PCB 307A	Nagra IV	"	58	Attn.
B2	"	"	Master 2500	"	"	"	21	50 db
B3	"	"	"	"	"	"	21	"
B4	"	"	"	"	"	"	14	"
C2	2000	0.0028	Okuma	B&K 4384	B&K 7005	"	31	3.16
C3	"	"	Type LS	"	"	"	15	"
C4	"	"	"	"	"	"	35	"
C7	"	"	"	"	"	"	15	"
C5	2000	0.0036	Okuma	B&K 4384	B&K 7005	"	12	3.16
C1	"	0.0031	Type LS	"	"	"	18	"
C6	"	0.0031	"	"	"	"	12	"

Table 5.1. Drilling data for 3.18 mm drill-size.

Drill Diameter : 6.35 mm (1/4 in)
Manufacturer : OSBORNE-MUSHET

Drill #	Speed (RPM)	Feed rate (in/rev)	Machine Tool	Acc. type	Tape Recorder	Workpiece Material	Total # of Hole	Vib. signal Gain
D1	1100	0.0052	Okuma	B&K 4384	B&K 7005	AISI	35	1
D2	"	0.0052	Type LS	"	"	4340	23	"
D3	"	"	"	"	"	"	26	"
D4	"	"	"	"	"	"	23	"
E1	1000	0.005	Harrison	PCB 307A	Nagra IV	AISI	39	Attn.
E2	"	"	M 400	"	"	4340	44	55 db

Table 5.2. Drilling data for 6.35 mm drill-size.

operation can be as high as Ø.6[42].

5.2. Time-amplitude signal.

There is a definite difference between the amplitude vs time signal for the 3.18 mm and 6.35 mm drill-sizes, as can be seen in Figures 5.1 and 5.2, respectively. Generally, for the 3.18 mm drill-size, the signal can be classified to be more uniformly distributed (denser) throughout each drilling sequence of about 3 seconds and there is an increase in the level of spikiness or amplitude level with wear, as can be seen in Figure 5.3. For the 6.35 mm drill-size, signals are less uniformly distributed as in the case for 3.18 mm drill-size, but significant increases in the level of spikiness or amplitude level are observed with wear, as shown in Figure 5.4. Vibration signals obtained with the 6.35 mm drill-size, generally speaking, exhibit a larger amplitude level than those for the 3.18 mm drills, roughly in the ratio of 5 to 1.

5.3. Tip wear curve.

As shown in Figure 5.5, there are four groups of tip wear curves observed in this research. That is, with chipping occuring at the cutting lips during the early part of the drilling process as shown by curve A, with a very rapid rate of tip wear and fails when levelling off as in curve B, an initial and final rapid wear phase separated by a normal section as shown by curve C, and lastly, curve D with a roughly opposite characteristics to that of C. Curve C corresponds reasonably

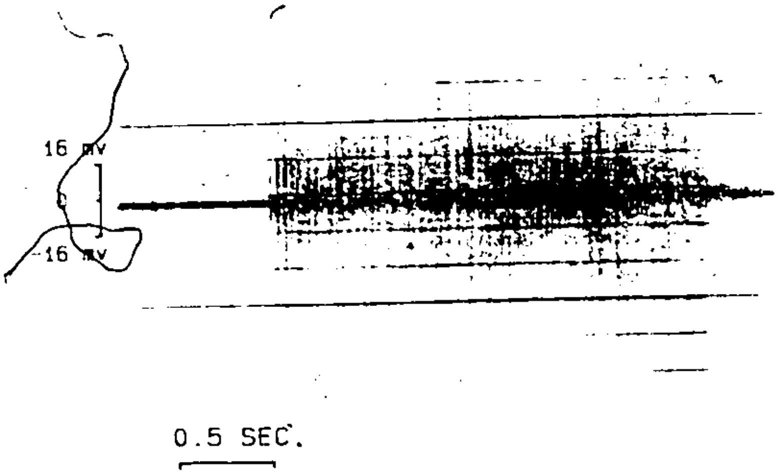


Figure 5.1 Vibration signal for 3.18 mm drill-size.

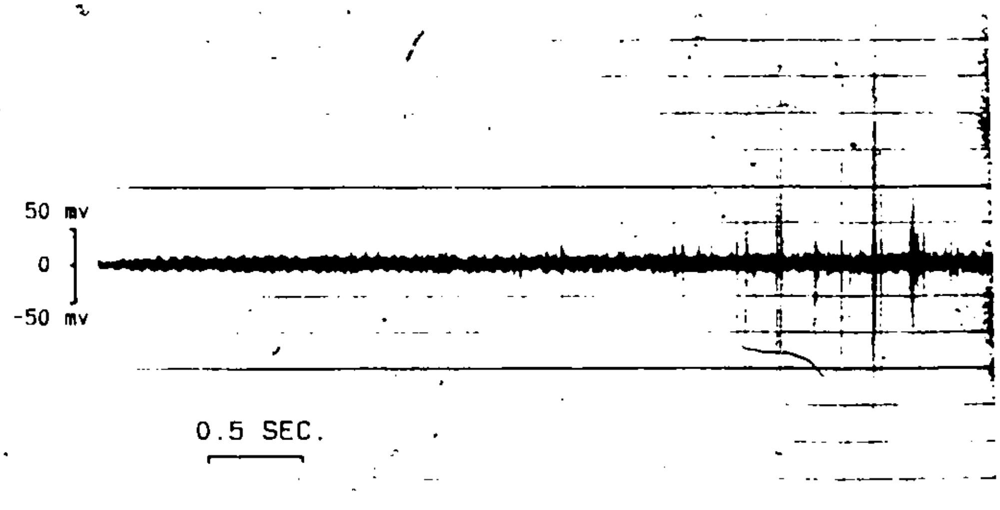


Figure 5.2 Vibration signal for 6.35 mm drill-size.

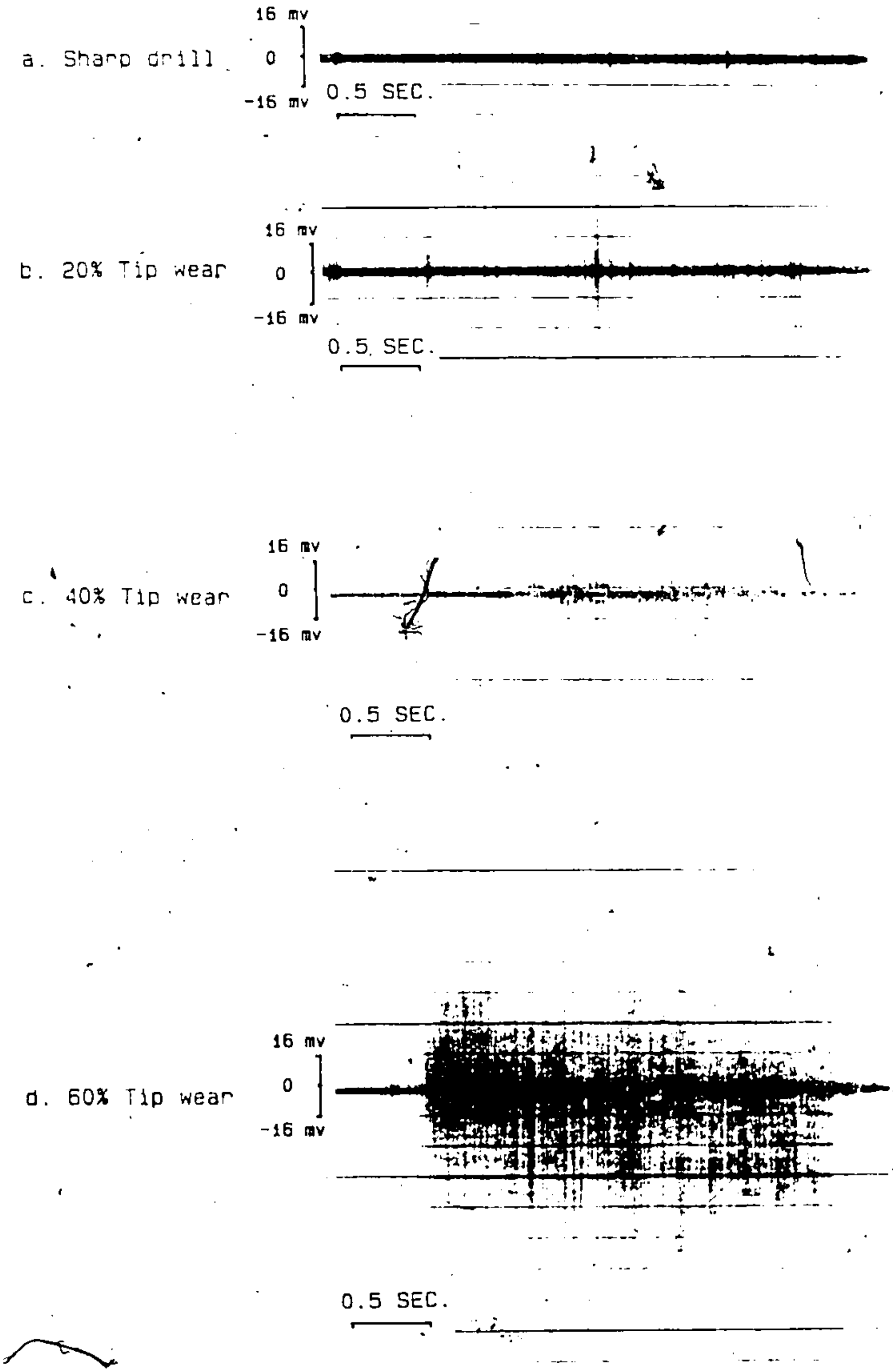


Figure 5.3 Vibration signals at various degree of tip wear for 3.18 mm drill-size.

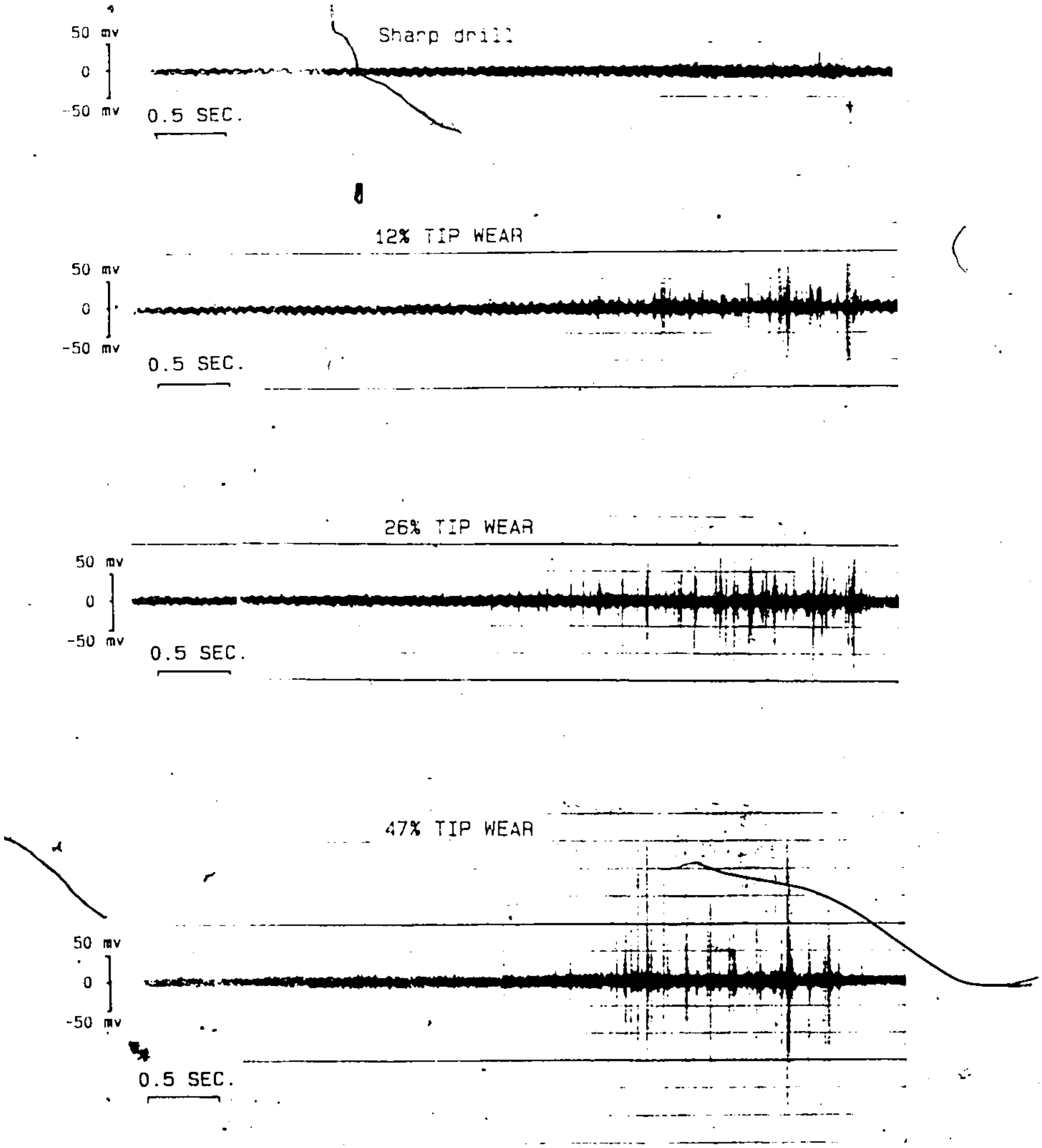


Figure 5.4 Vibration signals at various degree of tip wear for 6.35 mm drill-size.

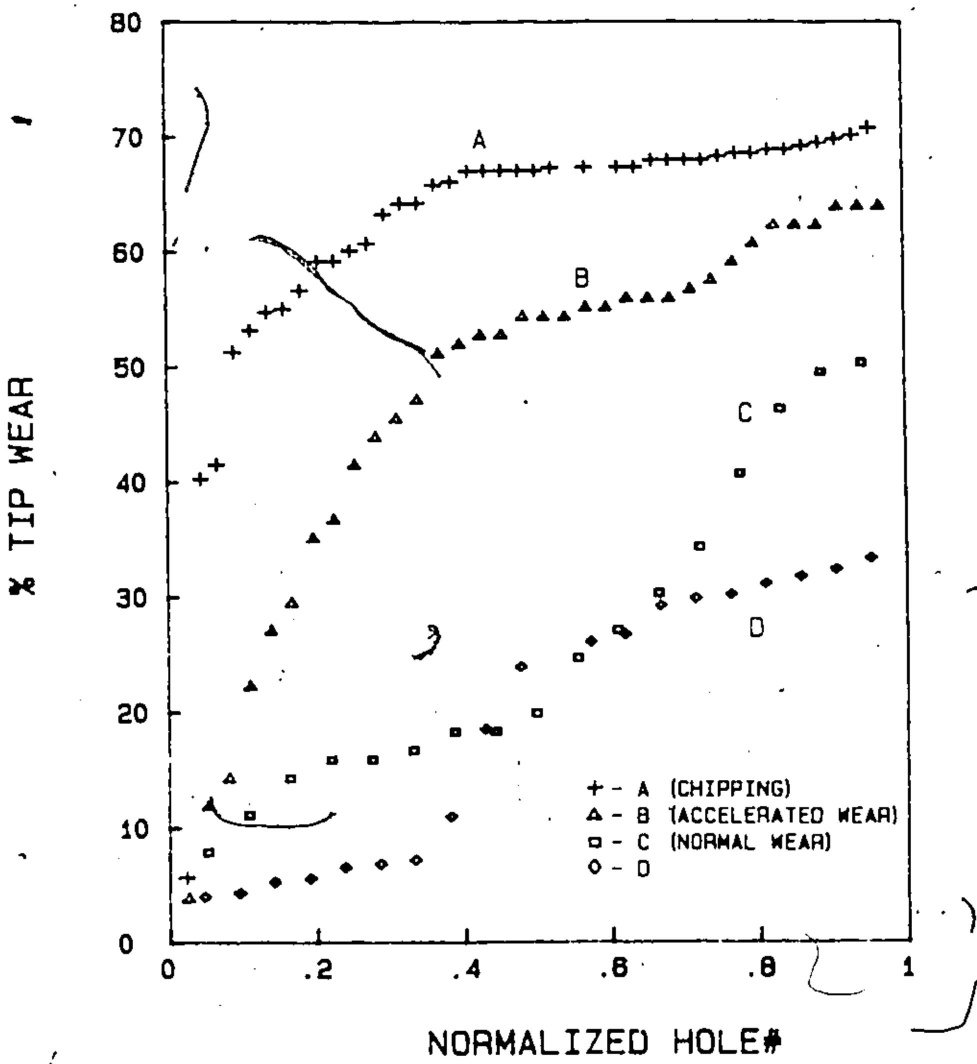


Figure 5.5 Typical set of tip wear curves observed.

close to normal drill wear and offers the best trend for wear monitoring.

An explanation of the behaviour of curve C is given in [6,37,60]. Initially when the drill is sharp, the real area of contact between the tool and workpiece A, is essentially zero, hence P/A, the uniaxial flow stress of the material, is much greater that Hb/3, a quantity related to the hardness of tool material, which results in a high wear rate. The rate of wear decreases as the value of A increases and eventually at a point where thermal softening occurs, the hardness of the material, Hb decreases, which again brings about a high wear rate until failure occurs. Of course, there are other factors that can influence the rate of wear, such as the tool and workpiece material history, its homogeniety, operating speed and feed rate, drilling machine, etc.

The machine tool also has some influence on drill-life, the type of dominant wear mechanism, and most of all, the vibration signal being picked up by the transducer. It is difficult to conclude at this point how the machine will influence the drill performance, but some indication of the effect by three machine tools is presented in Table 5.3. From the table, Harrison M400 seems to be the best among the three drilling machines, in term of the average drill-life obtained, assuming negligible effects due to the differential in the operating conditions.

Monitoring drill health for different drilling machines using vibration signals emitted during operation, is currently investigated in another project. There, more emphasis will be placed on establishing and identifying the different frequency components from the drilling machines or other related source during operations.

Drilling machine	Operating Speed (RPM)	conditions Feed rate (in/Rev)	Average Drill-life (holes)	Type of Tip wear curve
3.18 mm Drill diameter.				
Harrison M 400	2000	0.0004	35	A, C
Colchester Master 2500	1860	0.0004	29	C, D
Okuma Type LS	2000	0.0028	24	A, B, C
Okuma Type LS	2000	0.0036	12	B
Okuma Type LS	2000	0.0031	15	B, C
6.35 mm Drill diameter.				
Okuma Type LS	1100	0.0052	25	C
Harrison M 400	1000	0.005	42	C

Table 5.3. Drill performance on different drilling machine.

5.4. Statistical parameters.

5.4.1. statistical frequency distribution of the signals.

As mentioned before, time-amplitude signals were grouped before any statistical analysis was performed, mainly in order to reduce the analysis time involved. The grouped data known as the statistical frequency distribution for 3.18 mm drill-size can be seen in Figure 5.6. Generally, as the wear increases, the height of the distribution decreases with a corresponding increase in the spread/base of the distribution. Figure 5.7 shows the statistical frequency distribution of the vibration signals for 6.35 mm drill-size. In this case, the changes with wear are not as clearly defined as previously and significant changes can be observed only when tool failure is imminent, that is, when the tip wear is greater than 42 %.

5.4.2. Standard deviation and RMS of the distribution.

Plot of standard deviation versus percentage tip wear for the 3.18 mm drill size is shown in Figure 5.8. At approximately 60 percentage tip wear and standard deviation of 2 EU, the curve started to rise rapidly until failure. In other words, this stage of rapid increase in standard deviation signifies that drill failure is imminent and tool replacement is needed.

Figure 5.9 shows an inverse relationship of RMS of the distribution with percentage tip wear.

A definite trend exists between the standard deviation

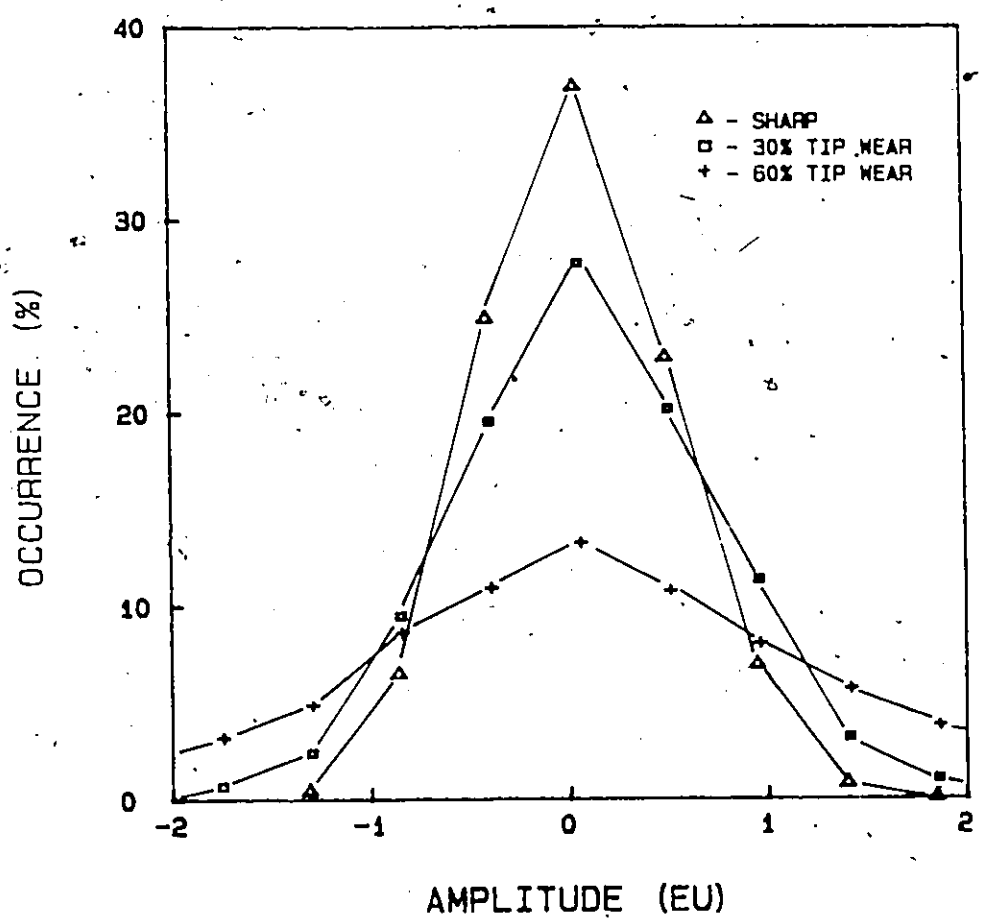


Figure 5.6 Statistical frequency distribution of 3.18 mm drill-size at various degree of tip wear.

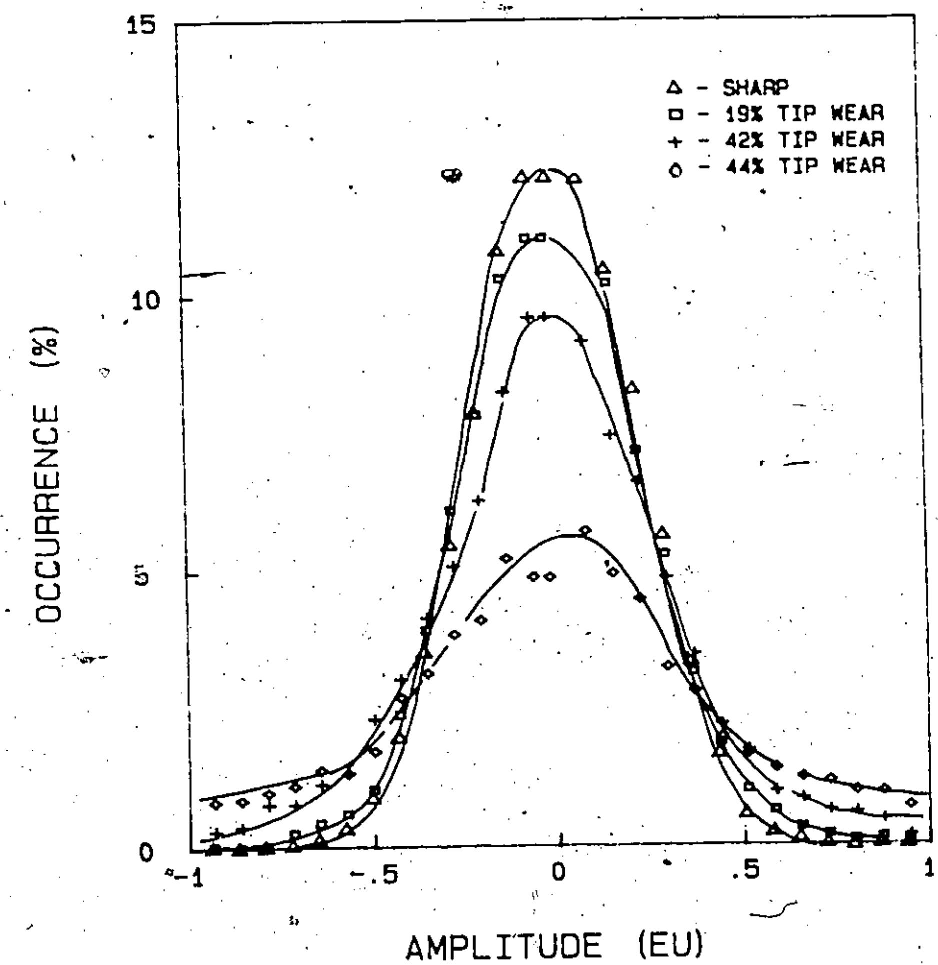


Figure 5.7 Statistical frequency distribution of 6.35 mm drill-size at various degree of tip wear.

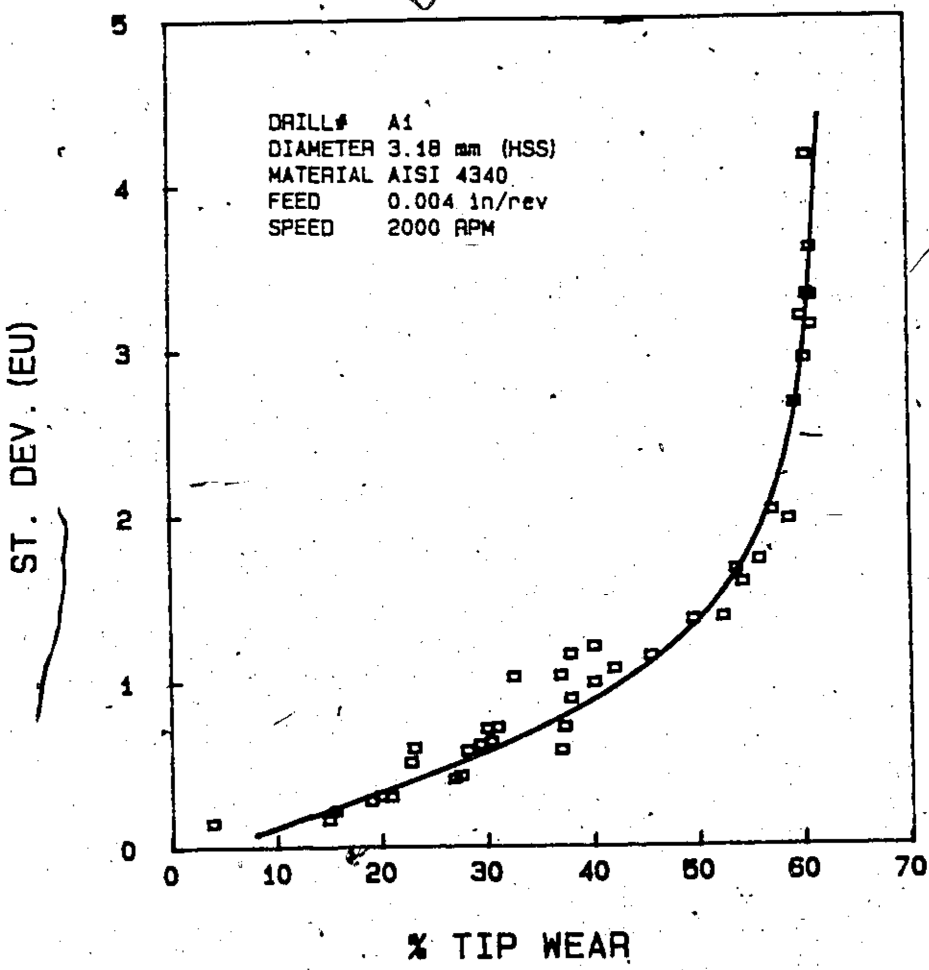


Figure 5.8 Plot of standard deviation versus percentage tip wear for 3.18 mm drill-size.

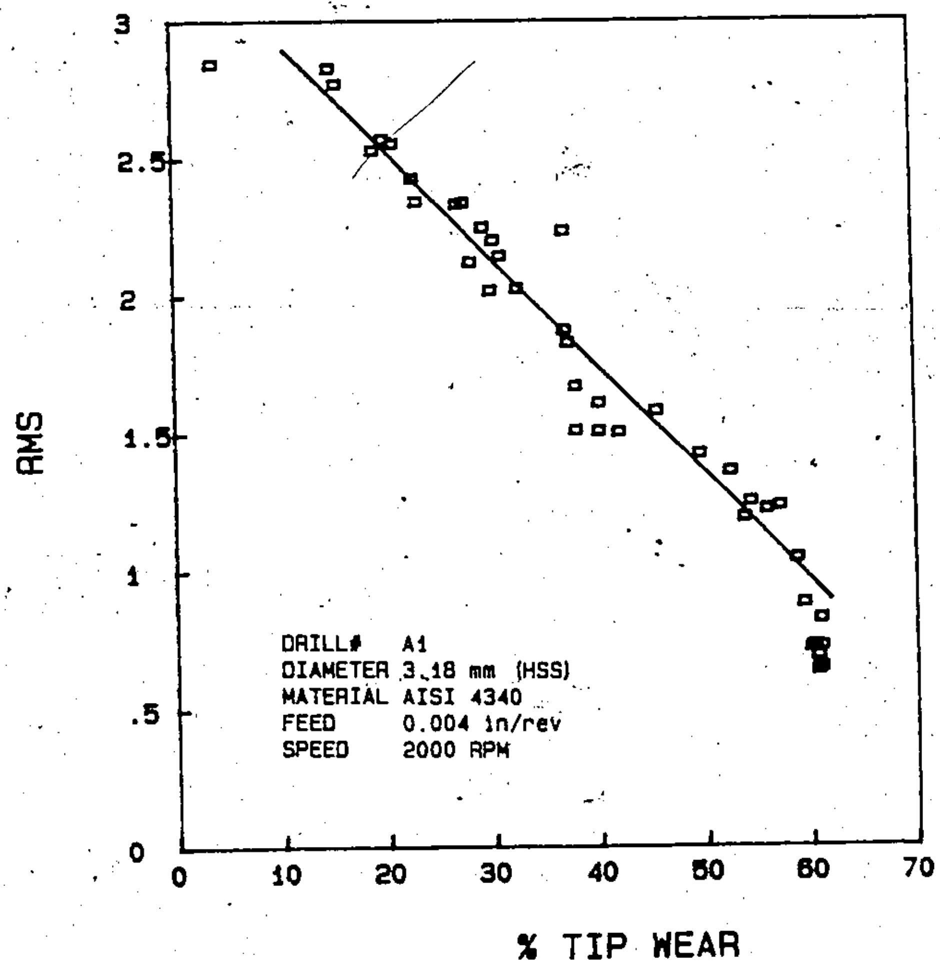


Figure 5.9 Plot of RMS of the distribution versus percentage tip wear for 3.18 mm drill-size.

and the RMS of the distribution against different groups of tip wear curves as mentioned before for different drilling machines. Table 5.4 gives an account of the values of those statistical discriptors and the related parameters at that instant when rapid changes occur.

Drilling machine	Drill number	St. Dev. (EU)	RMS	% Tip wear	% Life Used
Harrison M 400	A1	2	1.2	57	81
	A2	6.25	1.1	69	73
	A3	6	1.1	68	70
	A4	6.1	1	63	68
Colchester Master 2500	B1	2	1.5	40	60
	B2	2	1.8	27	66
	B3	2	1.7	29	71
Okuma Type LS	C1	1	1.2	45	83
	C2	1	1.3	54	74
	C3	0.9	1.5	38	73
	C4	0.9	1.3	60	77
	C5	1.05	1.4	42	75
	C6	1.1	1.3	46	67
	C7	1.04	1.4	36	80

Table 5.4. Standard deviation and RMS of the distribution for 3.18 mm drill-size.

As can be seen in Table 5.4, for different drilling machines, different standard deviation and RMS values are observed. It was found that standard deviation does vary to some degree with type of drill wear occuring at the cutting lips and this variation is dependent on the type of drilling machine. For instance, Harrison M-400 lathe induces a significant drill wear at the cutting lips. Drill# A1 exhibits a normal type of wear and the observed standard deviation is 2 whereas the rest with some chipping on the lips have a value of about 6. The RMS was found to be around 1.1 for all cases. As for the other two lathes, the standard deviation was found to be around 2 and 1 and the corresponding RMS values of 1.7 and 1.3, regardless of the type of drill wear involved during the operation.

The above observations can be reproduced reasonably consistently for the 3.18 mm drill-size. However, for the drill-size of 6.35 mm, only a very weak relationships exists mainly due to the nature of vibration signals generated during the drilling process, namely, the uniformity and the denseness of the vibration signal together with its level of spikiness. The plot of standard deviation and RMS of the distribution with percentage tip wear are shown in Figures 5.10 and 5.11, respectively.

5.4.3. Mean values.

Mean values of the signal for both 3.18 mm and 6.35 mm drill-size remained fairly constant at 0 volts at all time as shown in Figure 5.12.

5.4.4. Skew and kurtosis values.

A typical plot of skew and kurtosis values versus percentage tip wear for 3.18 mm drill-size can be seen in Figures 5.13 and 5.14, respectively. In both plots, large and cyclic fluctuations in the values occur for a major portion of the

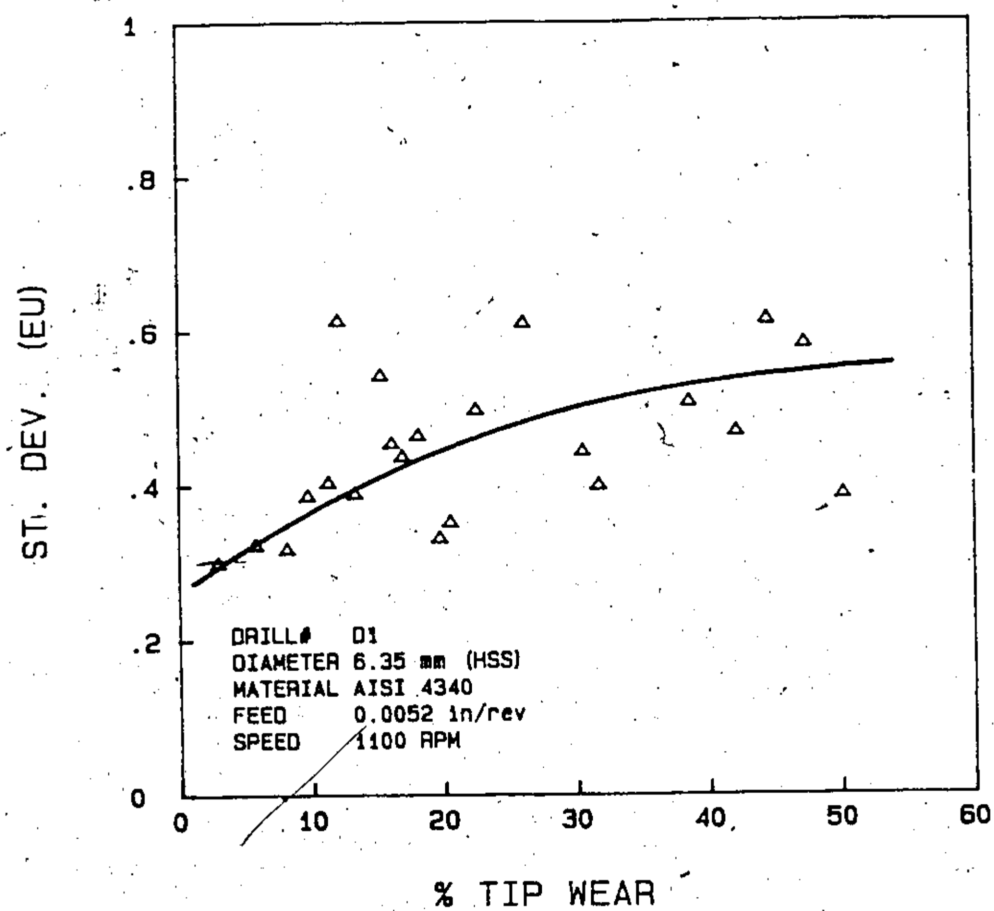


Figure 5.10 Plot of standard deviation versus percantage tip wear for 6.35mm drill-size.

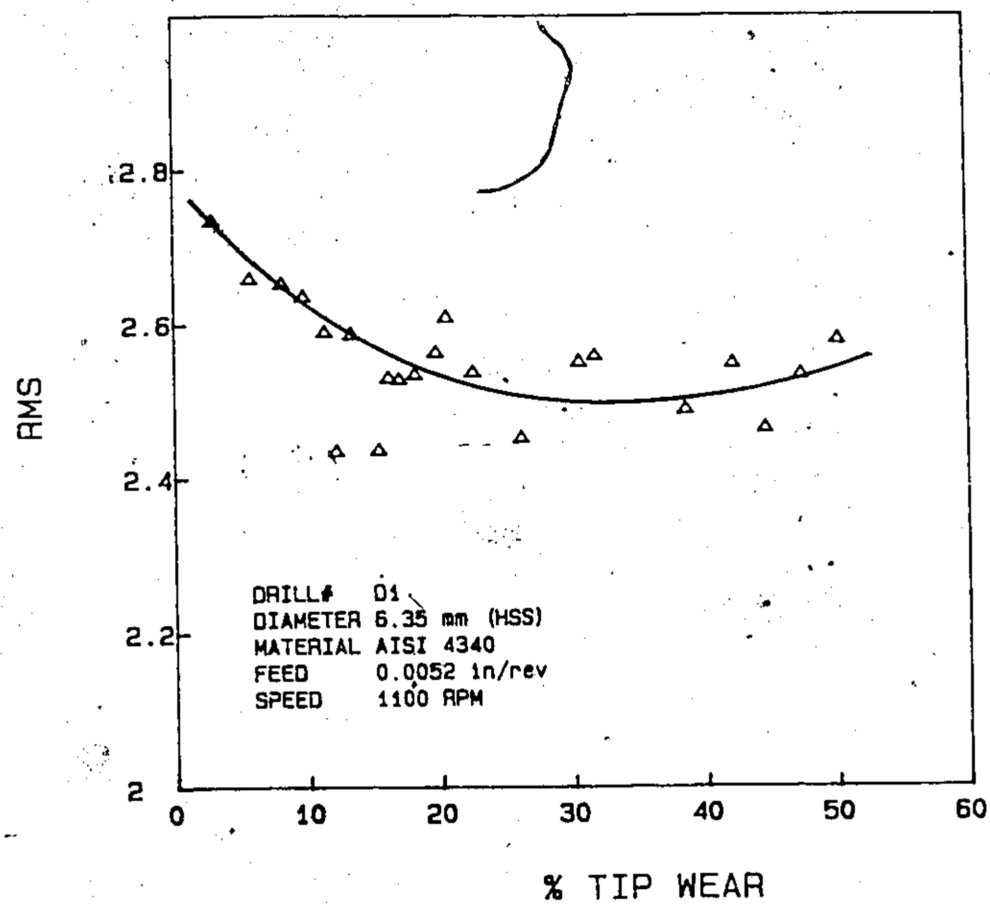


Figure 5.11 Plot of RMS of the distribution versus percentage tip wear for 6.35mm drill-size.

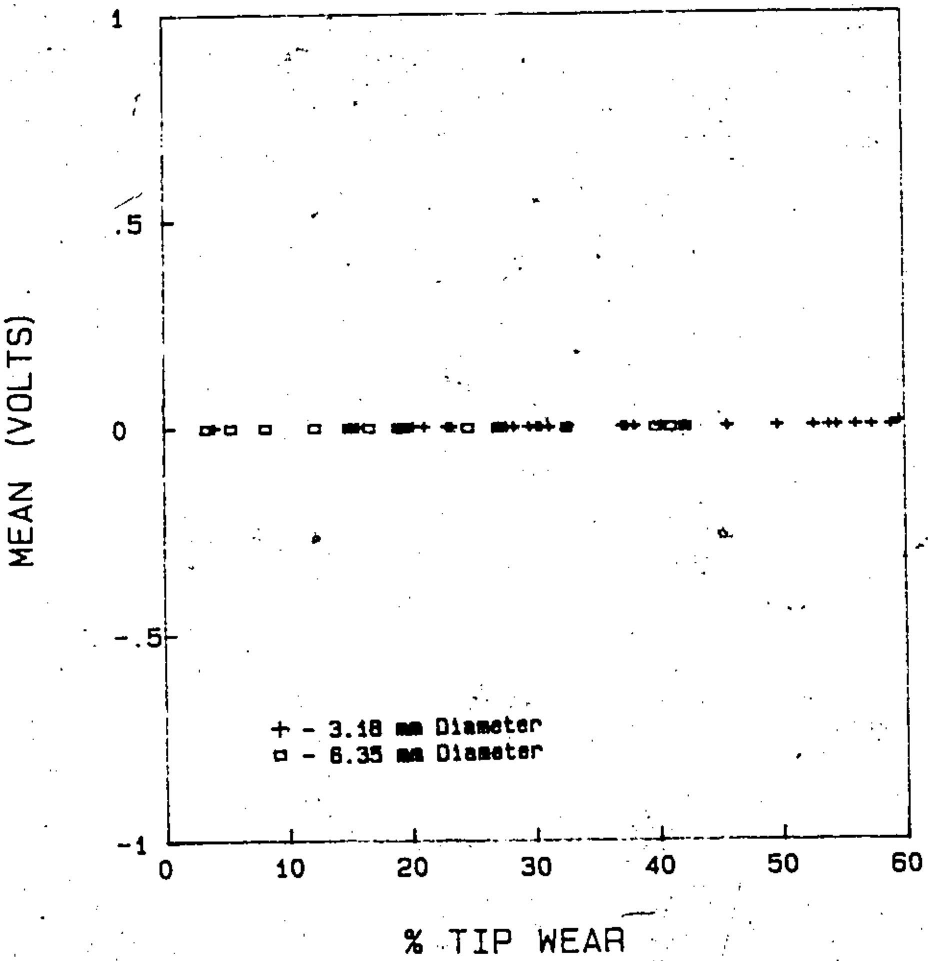


Figure 5.12 Plot of mean versus percentage tip wear.

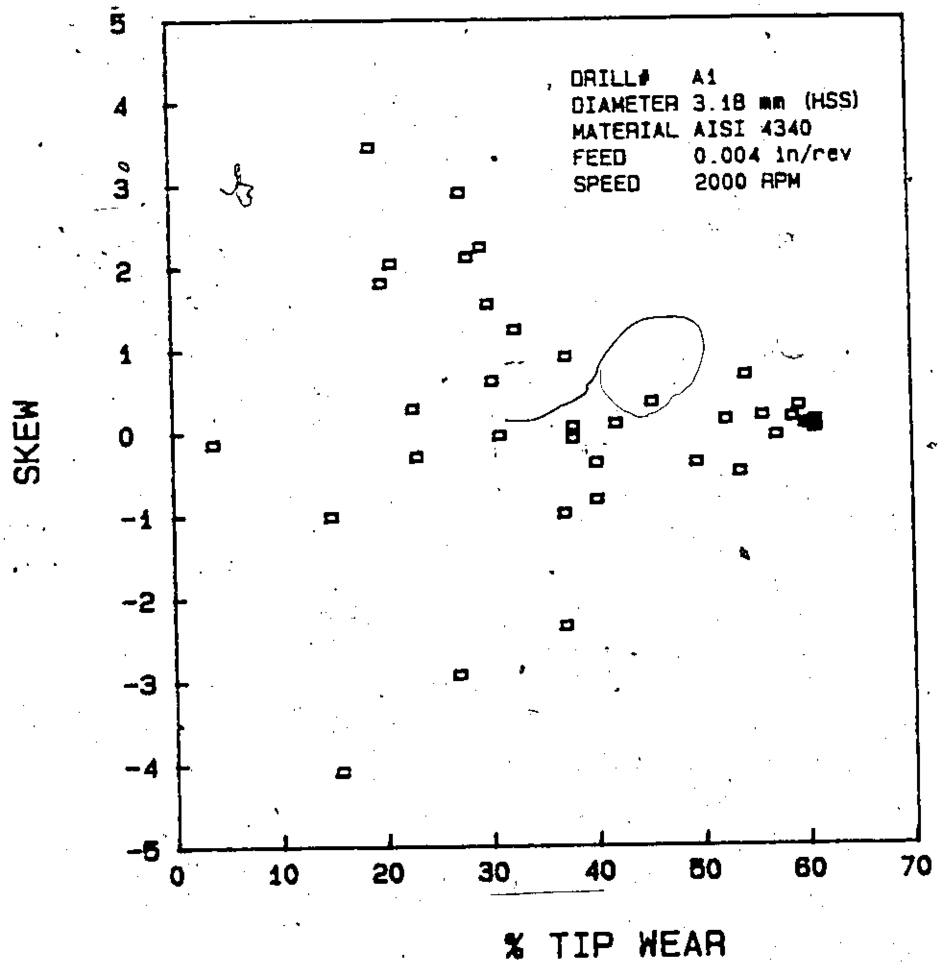


Figure 5.13 Plot of skew versus percentage tip wear for 3.18 mm drill-size.

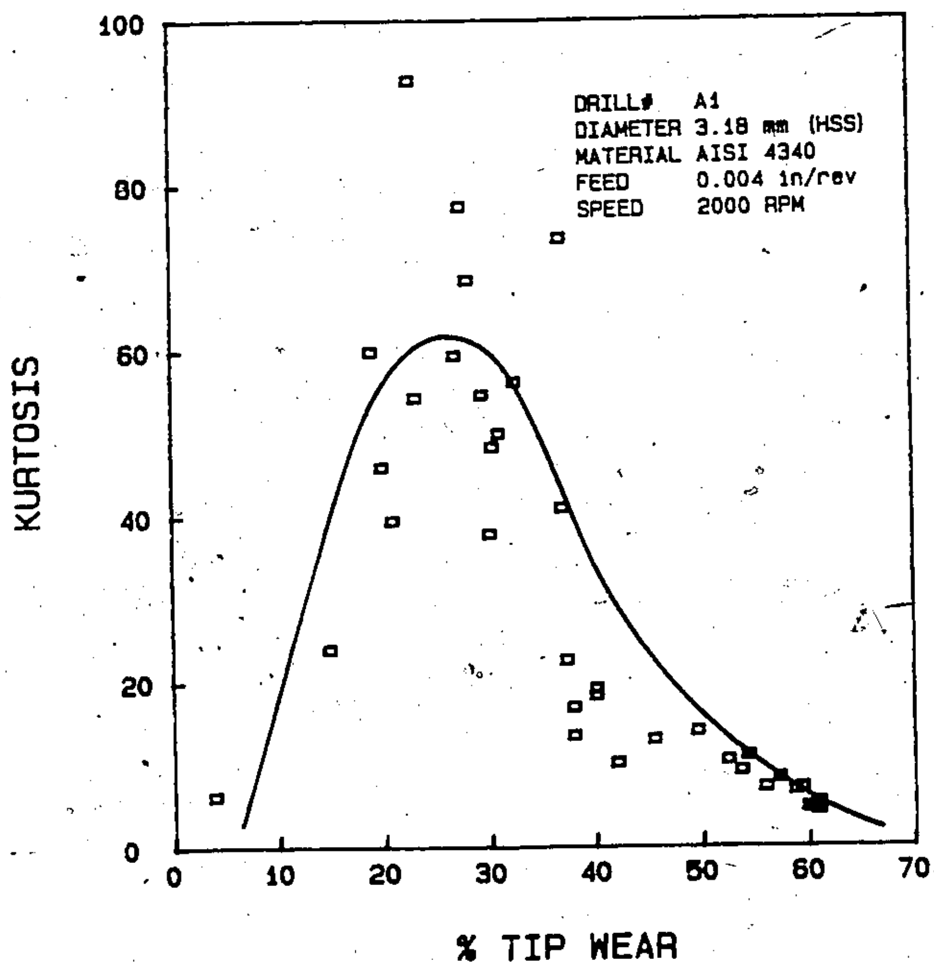


Figure 5.14 Plot of kurtosis versus percentage tip wear for 3.18 mm drill-size.

tool-life, except at the initial portion and the portion just prior to tool failure. As mentioned before, in the section on "Analysis of data", those two descriptors are somewhat sensitive to the spread of the distribution, especially in cases with few peaks that are clearly distinct from the rest.

In a tool wear model, presented by Braun, Lenz and Wu [10], it was stated that due to production tolerances a drill is slightly asymmetric, hence it only wears at one lip until the heights of both lips are equal. The second lip, which is now sharper, starts cutting more. Depending on the dullness of the cutting lips, different vibration levels are observed. This alternating process continues until both lips have no more clearance at the margin. At this time, the drill sticks to the workpiece and breaks if the drilling process is not stopped in time. This model of an alternate wearing process at the cutting lips is suggested by the cyclic-fluctuating values of skew and kurtosis, as shown in Figures 5.13 and 5.14, respectively. The magnitude of the fluctuation is dependent upon the differences in sharpness between the two lips and also the stage of the tool's condition. Just prior to tool failure, both lips are having the same degree of dullness and bring about a high level of vibration, hence give rise to small values of skew and kurtosis. The state of convergency of this two descriptors, in general, corresponds to the situation when the drill is about to fail and to a significant change in the standard deviation and RMS of the distribution. Table 5.5 shows the skew and kurtosis values at the above mentioned state. As can be seen from the values at the above mentioned state. As can be seen from the Table, skew does not show any consistency in values at the state just prior to drill failure, however it is a small number. On the other hand, depending on the type of drilling machine, different kurtosis values are obtained. For Harrison M-400, the kurtosis value is about 8 whereas the other two lathes have the value of about 19.

Drilling machine	Drill number	skew	Kurtosis
Harrison M 400	A1	-0.04	8
	A2	-0.19	7.7
	A3	0.02	8
	A4	0.01	5.2
Colchester Master 2500	B1	0.59	19
	B2	-0.4	19
	B3	-1.2	19
Okuma Type LS	C1	-0.5	15
	C2	0.08	12
	C3	-1.3	17
	C4	0.33	22
	C5	-1.1	19
	C6	-1.3	21
	C7	-0.9	19

Table 5.5. Skew and kurtosis values when breakage is imminent.

However, due to the lower density and high level of spikiness of the vibration signal for the 6.35 mm drill-size, which give rise to a large spread in the frequency distribution, no promising relationships of skew and kurtosis with wear were found, as can be seen in Figures 5.15 and 5.16, respectively.

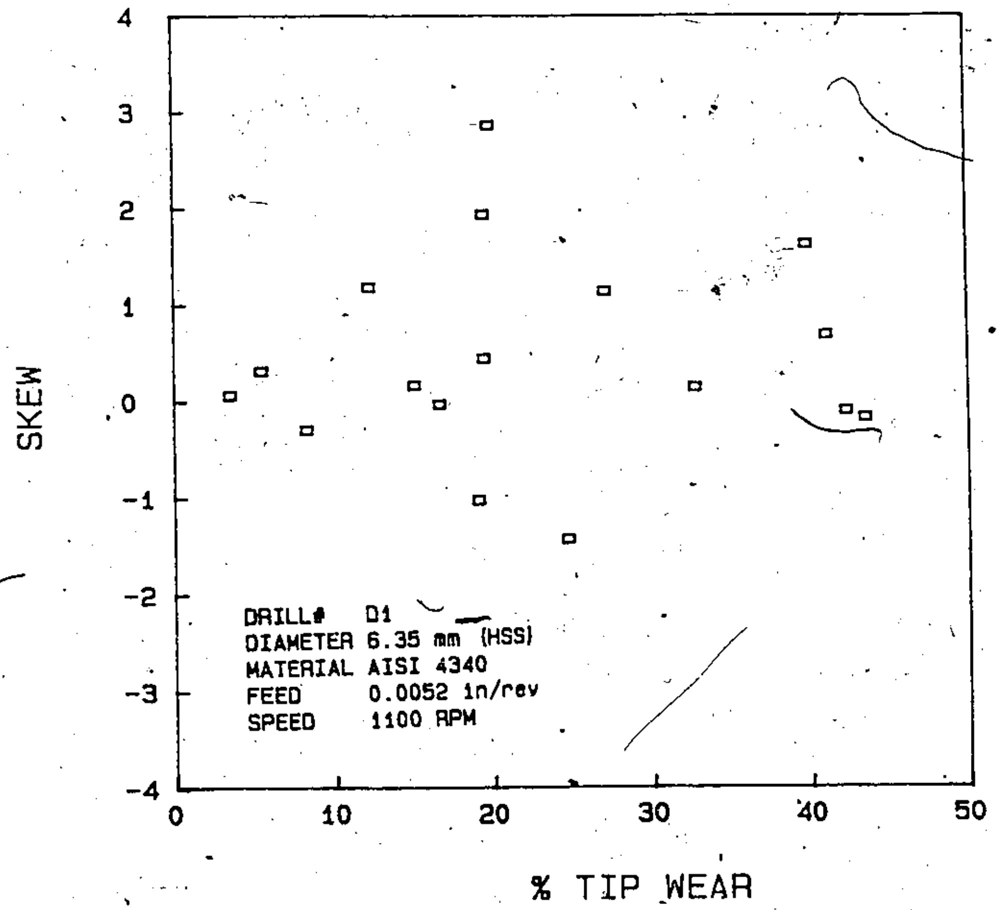


Figure 5.15 Plot of skew versus percentage tip wear for 6.35 mm drill-size.

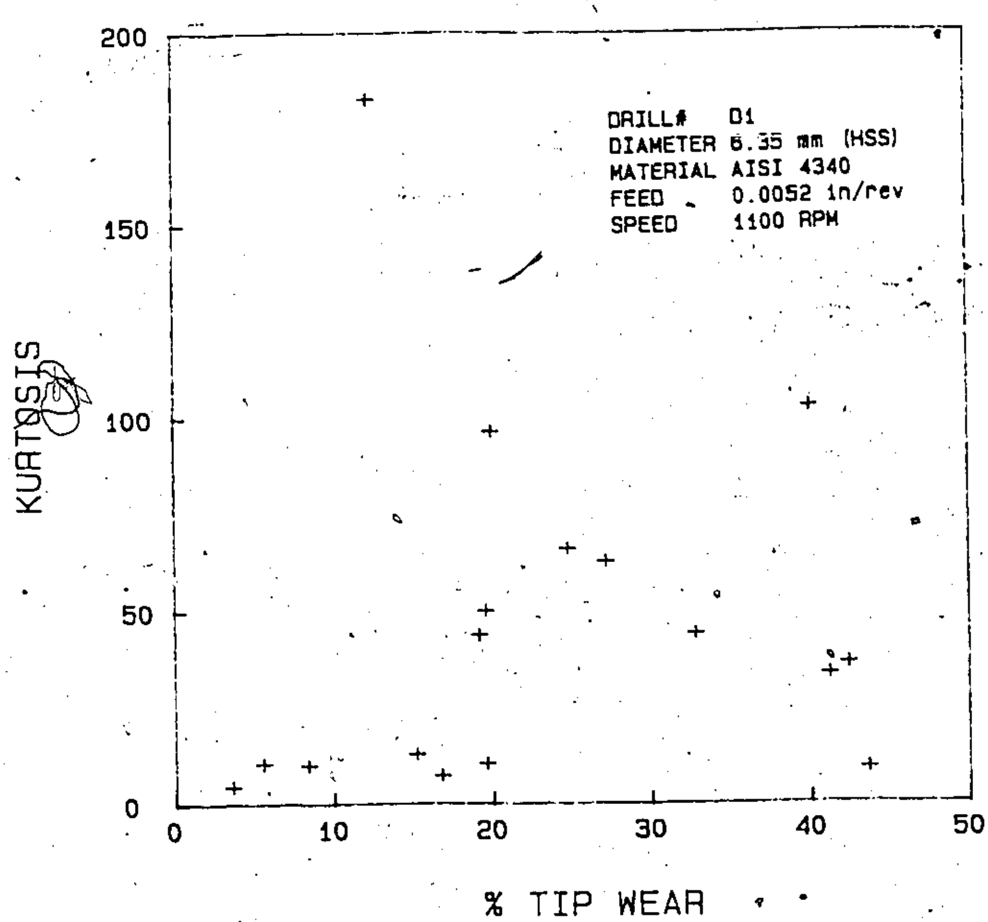


Figure 5.16 Plot of kurtosis versus percentage tip wear for 6.35 mm drill-size.

Due to the distinct characteristic behaviour of standard deviation and RMS of the distribution with tip wear, another descriptor, namely, variance/RMS was developed. This descriptor, improves the sensitivity to tip wear and exhibits a significant rise in the curve when failure is imminent as shown in Figure 5.17; however, it is not good for 6.35mm diameter drill bits.

5.5. Influence of the number of sampled points on the statistical results.

The number of digitized points chosen in this project illustrates a compromise between the computer memory available and the time involved in drilling a hole. It was accomplished by introducing some sample interval delay when required, as described before. Two drills, drill# C2 of 3.18 mm diameter and drill# E1 of 6.35 mm diameter were chosen in the study because they both exhibited a closely normal type of tip wear curve. Due to the limited capacity of the computer memory, the maximum number of sampled points allowed is 6000. Hence, six groups of sampled points were chosen, namely 1000, 1200, 1500, 2000, 3000 and 6000. A selective number of vibration signals were picked for the evaluation, as shown in Table 5.6.

In general, standard deviation and RMS of the distribution are not that sensitive to the number of sampled points taken as can be seen in Figures 5.18, 5.19, 5.20 and 5.21. Each cross on the plot denotes a descriptor's value at a specific number of sampled point. The spread of those crosses illustrates the sensitivity of the descriptor to the number of sampled

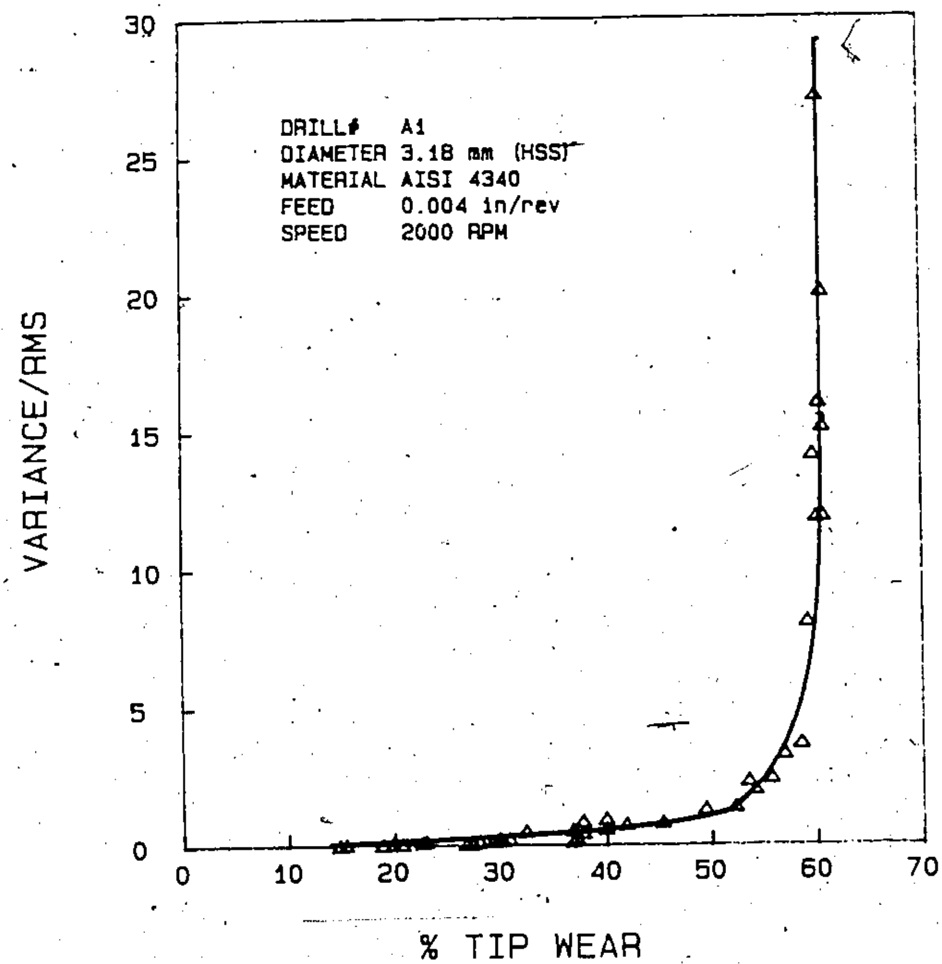


Figure 5.17 Plot of variance/RMS versus percentage tip wear for 3.18 mm drill-size.

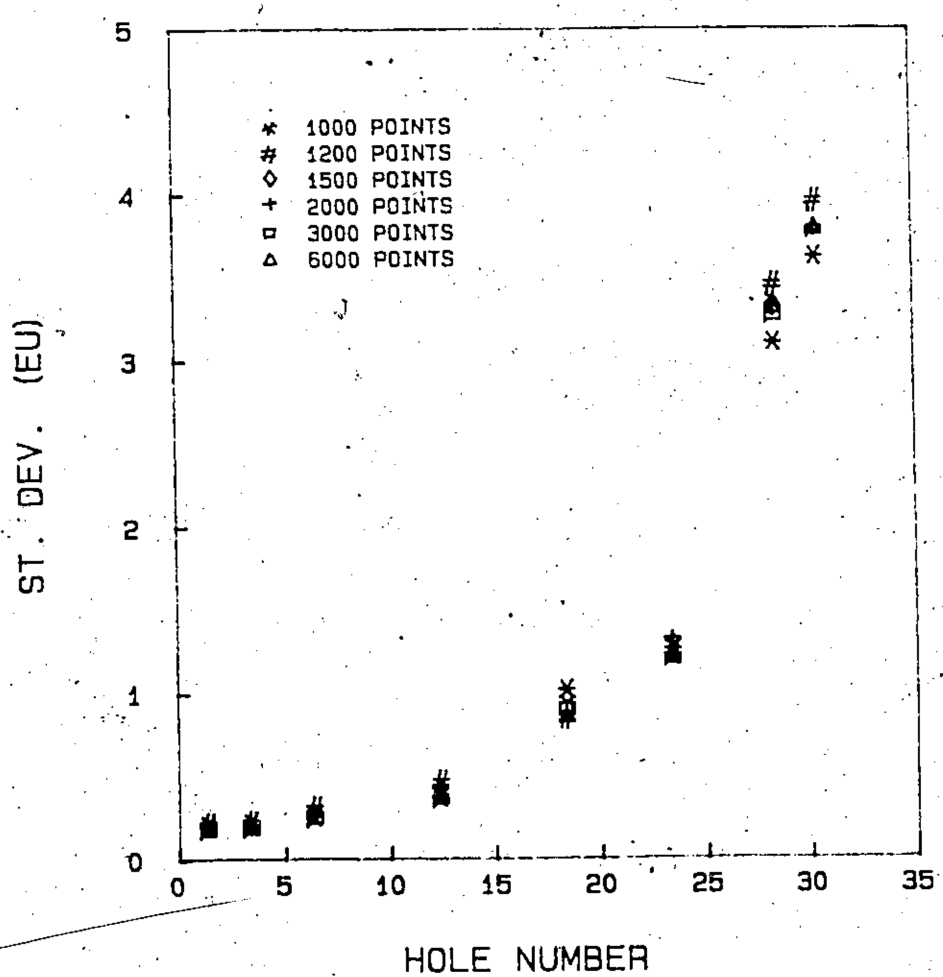


Figure 5.18 Effects of sample sizes on standard deviation for 3.18 mm drill-size.

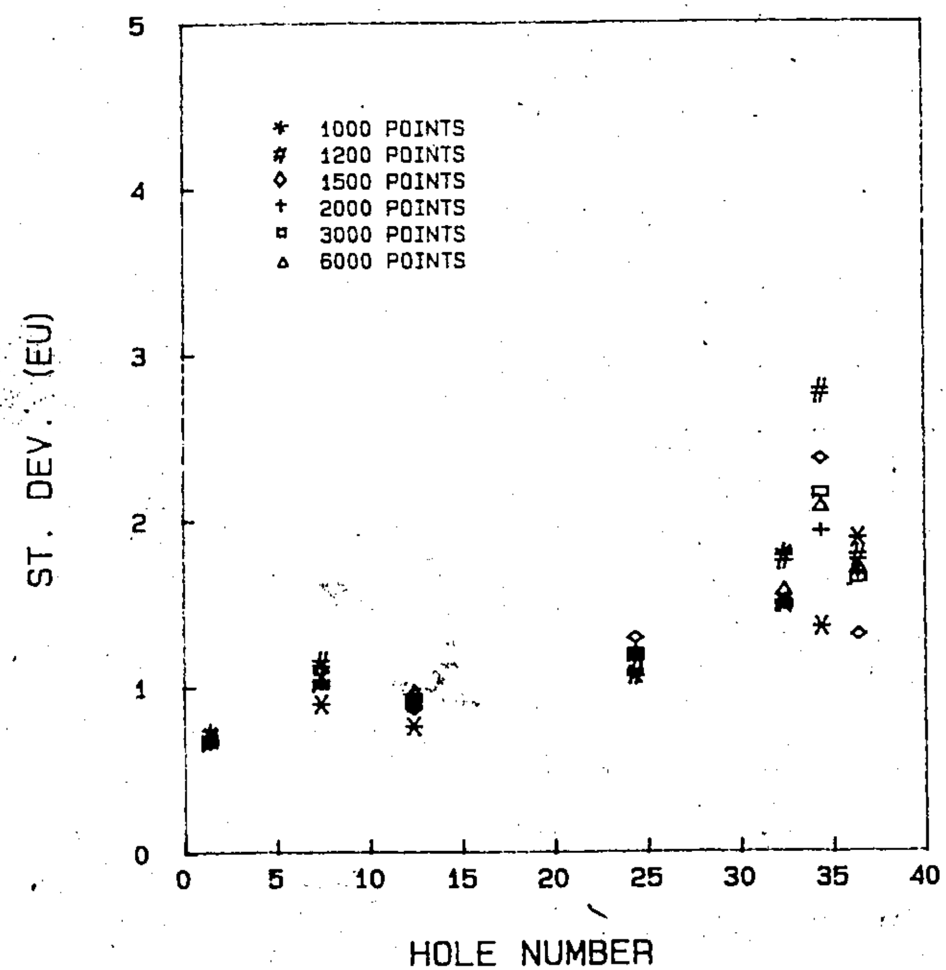


Figure 5.19 Effects of sample sizes on standard deviation for 6.35 mm drill-size.

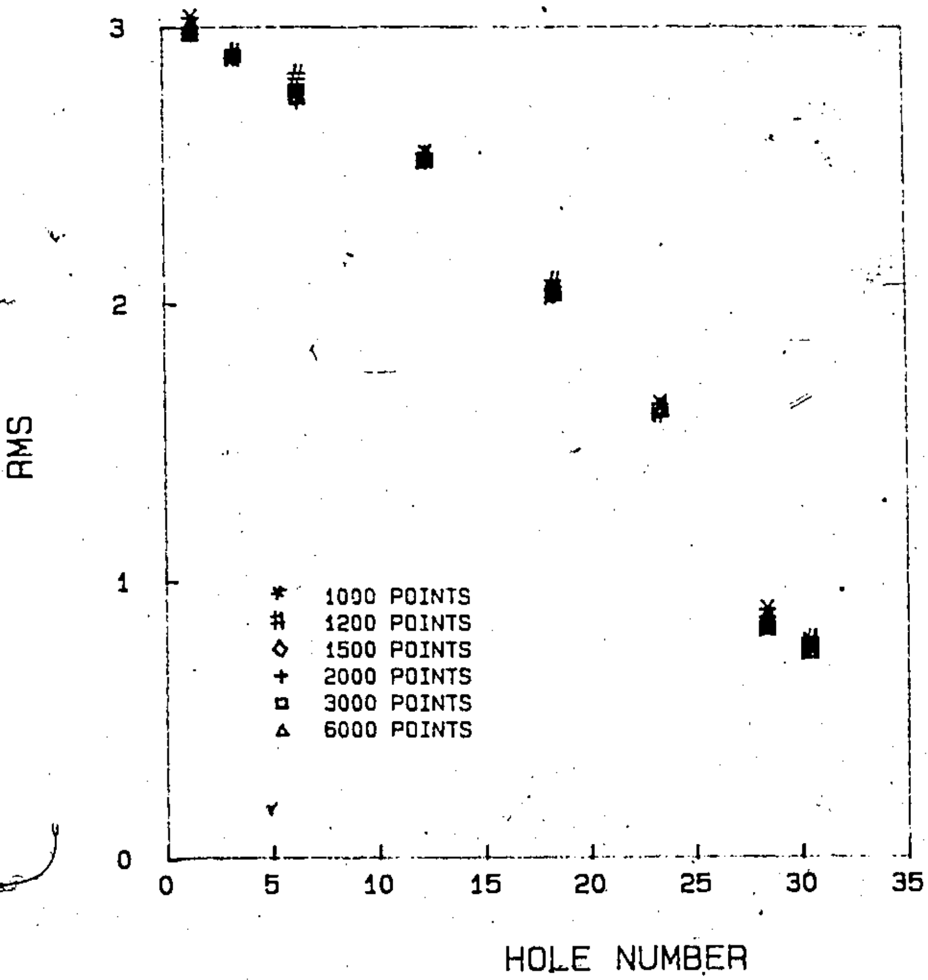


Figure 5.20 Effects of sample sizes on RMS of the distribution for 3.18 mm drill-size.

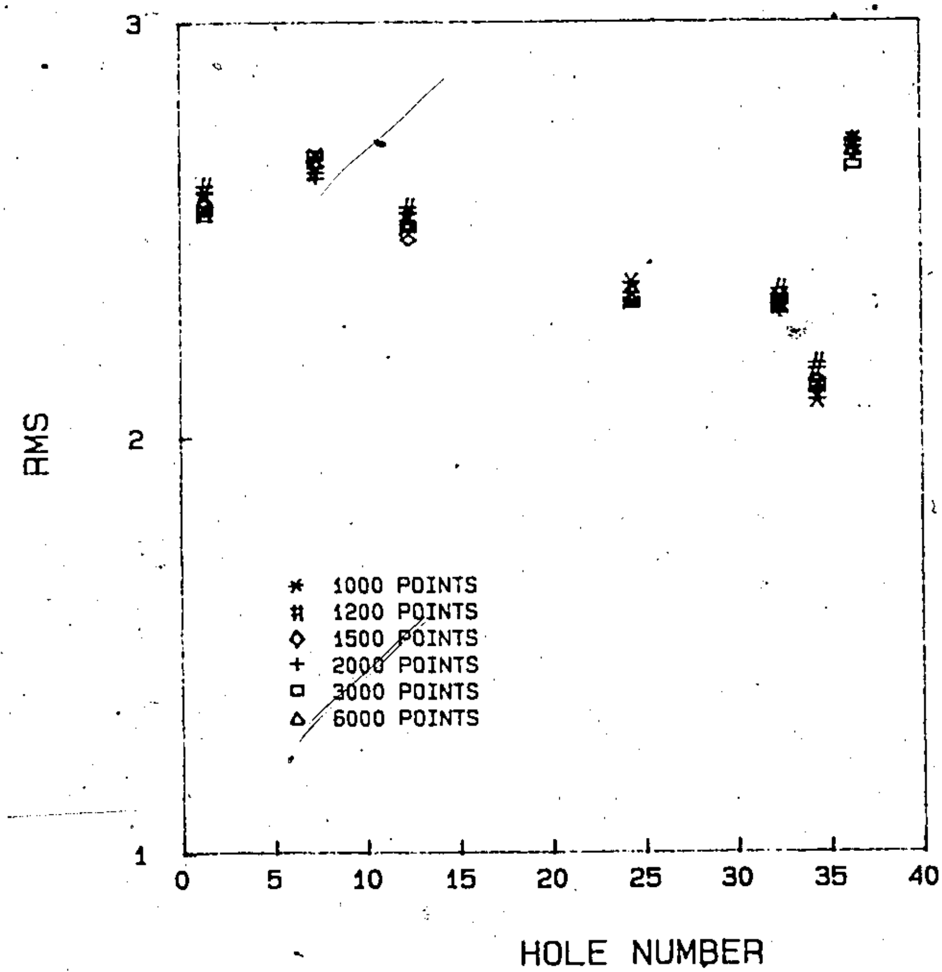


Figure 5.21 Effects of sample sizes on RMS of the distribution for 6.35 mm drill-size.

points.

Skew and kurtosis, on the other hand, are very sensitive to the number of sampled points taken if the vibration signal is spiky, as is illustrated for the 6.35 mm drill-size shown in Figures 5.22 and 5.23.

Vibration signals for 3.18 mm diameter drill bits, generally change from a low amplitude and dense form, signifying sharp drilling, to transitional stage where the level of spikiness increases, and finally to a very dense and high amplitute form denoting that failure is imminent. During these transitional stages of the signals, skew and kurtosis are very sensitive to the number of sampled points taken as shown in Figures 5.24 and 5.25.

DRILL# C2 (3.18 mm)

Hole #	1	3	6	12	18	23	28	30
% tip wear	sharp	10	20	40	50	54	60	63

DRILL# E1 (6.35 mm)

Hole #	1	7	12	24	32	36	38
% tip wear	sharp	13	18	29	40	42	43

Table 5.6. Vibration signals used to study the influence of the number of sampled points on the statistical results.

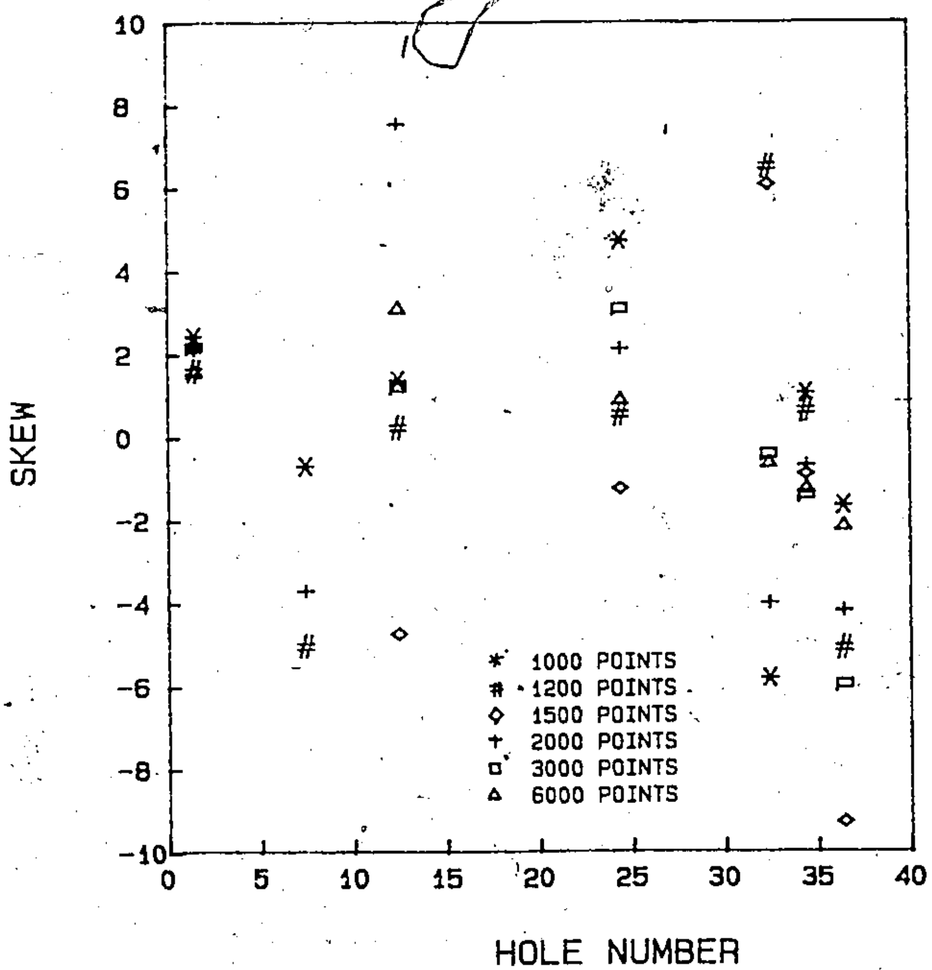


Figure 5.22 Effects of sample sizes on skew for 6.35 mm drill-size.

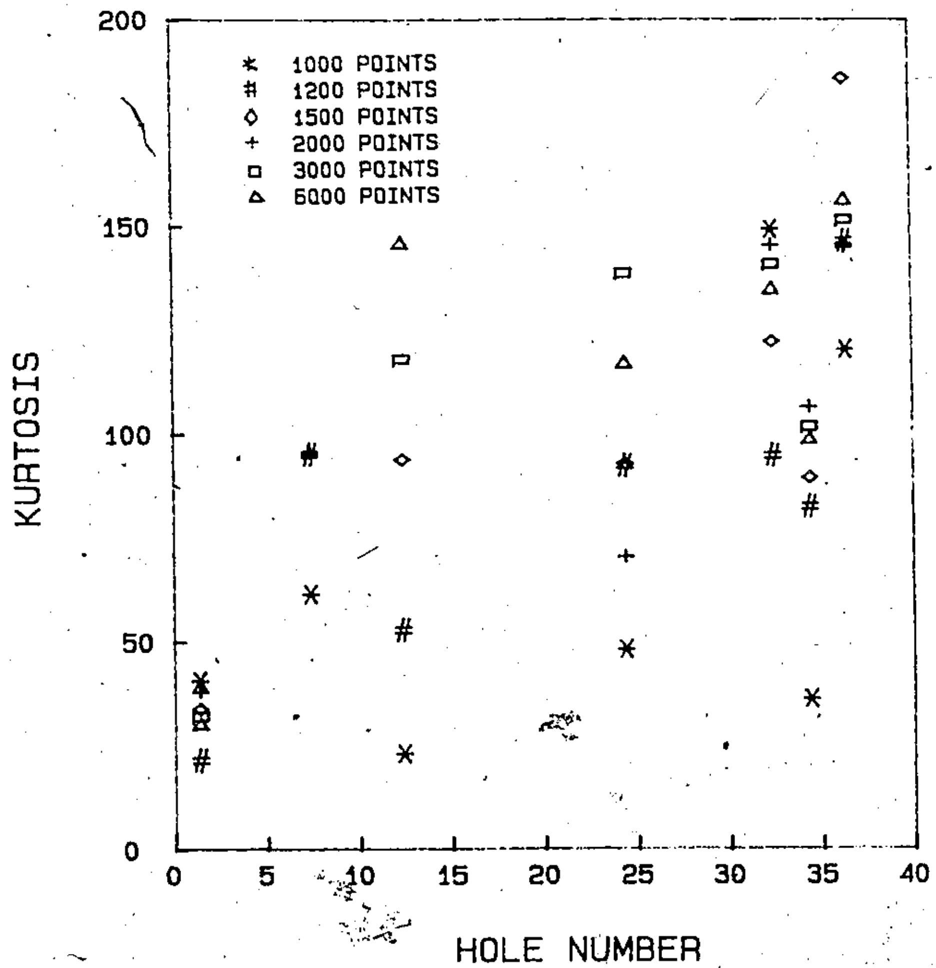


Figure 5.23 Effects of sample sizes on kurtosis for 6.35 mm drill-size.

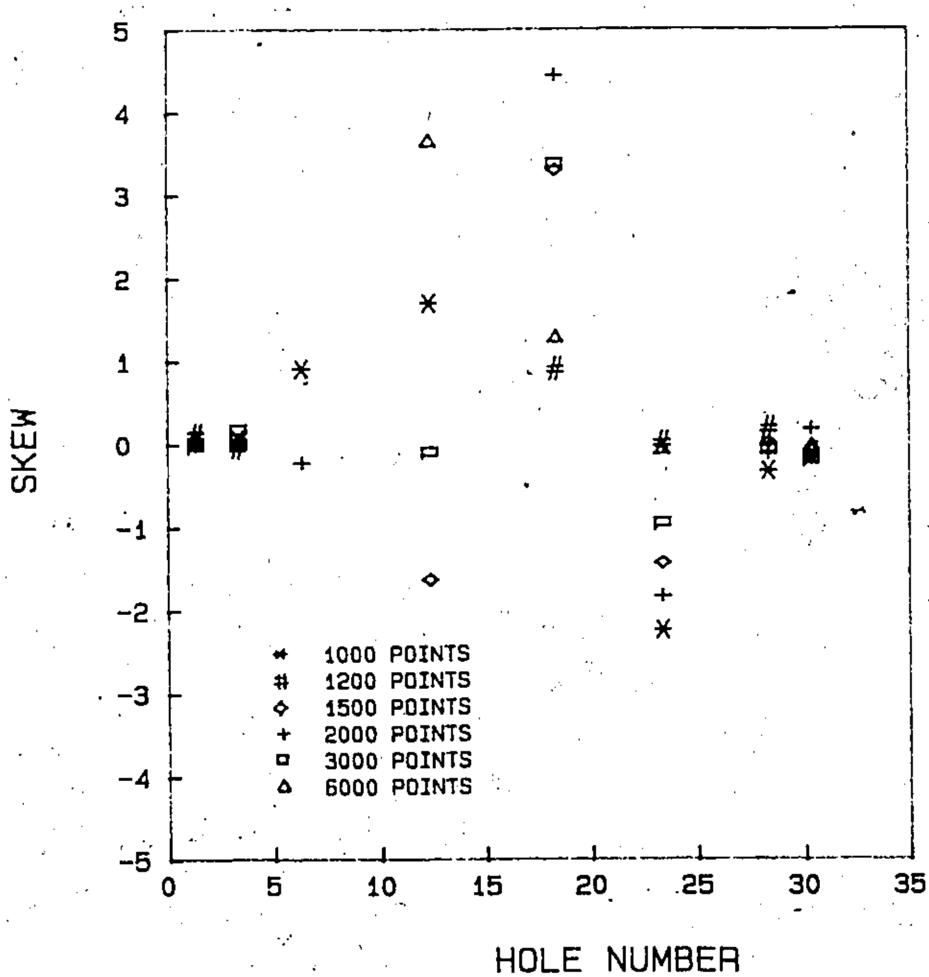


Figure 5.24 Effects of sample sizes on skew for 3.18 mm drill-size.

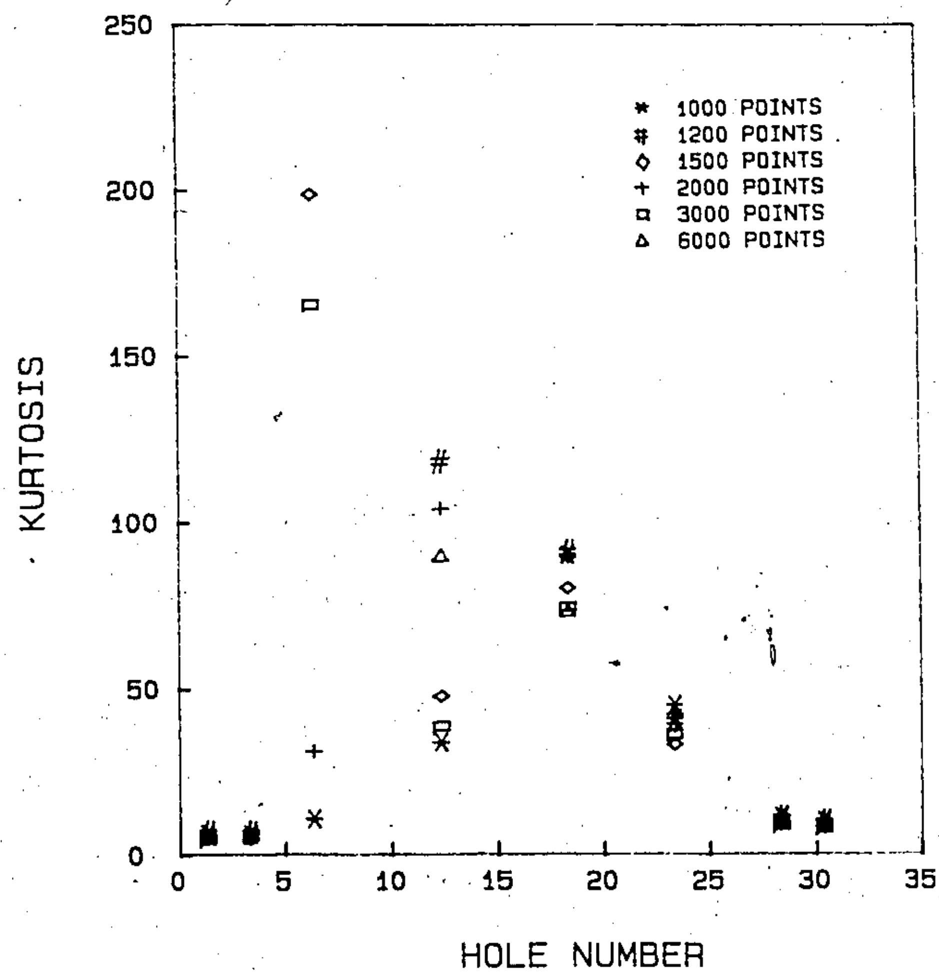


Figure 5.25 Effects of sample sizes on kurtosis for 3.18 mm drill-size.

5.6. Consistency of the statistical results.

5.6.1. 3.18 mm diameter drill bits.

Four drills, namely drill# C1, C2, C3 and C4 from a same drilling machine, Okuma type LS, were picked in the study. Under the same operating conditions, a very consistent trend of standard deviation and RMS of the distribution Vs normalized tip wear were obtained as shown in Figures 5.26 and 5.27, respectively. Figure 5.28, plot of variance/RMS Vs normalized tip wear, shows a very significant upward trend when normalized tip wear is greater than Ø.8. Skew and kurtosis, on the other hand, do not show consistency in the results except when failure is imminent as shown in Figure 5.29 and Figure 5.3Ø, respectively.

5.6.2. 6.35 mm diameter drill bits.

Three drills drilled on Okuma type LS lathe were picked, namely drill# D1, D2 and D3. There exists a weak correlation between standard deviation, RMS of the distribution and variance/RMS with the normalized tip wear as shown in Figures 5.31, 5.32 and 5.33, respectively. No consistency in the skew and kurtosis with normalized tip wear as shown in figures 5.34 and 5.35.

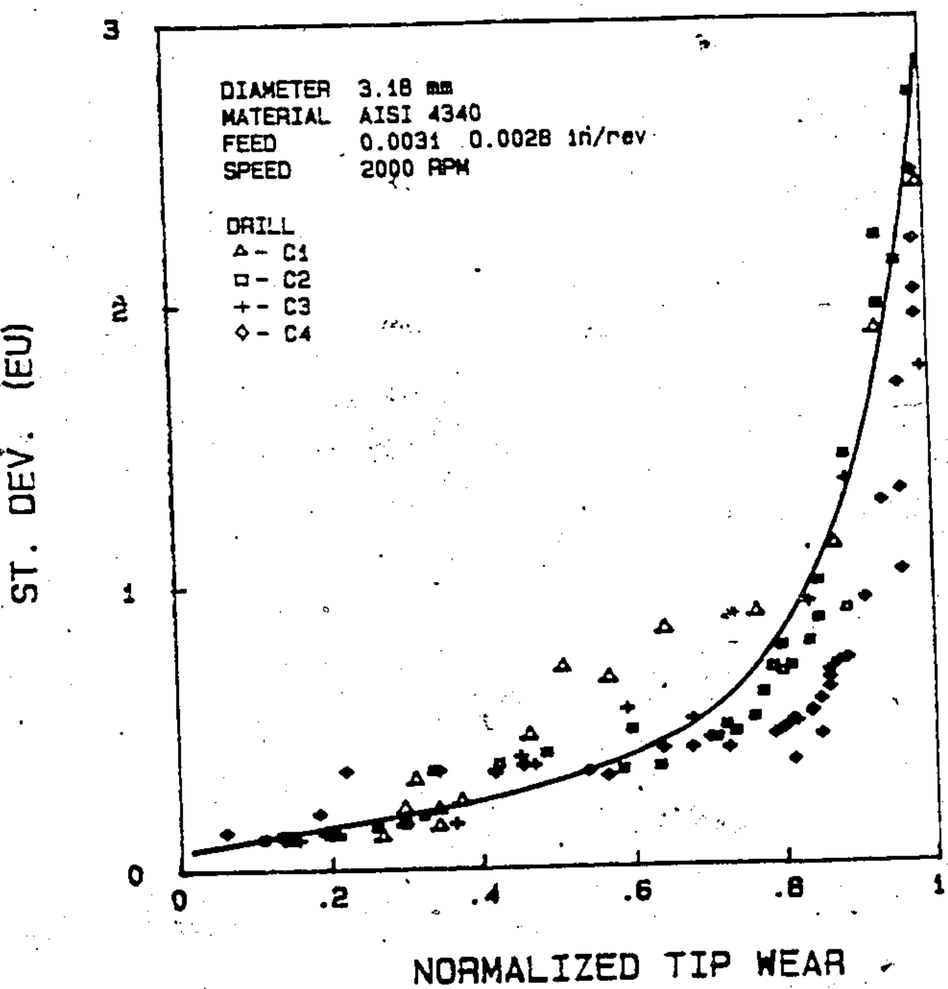


Figure 5.26 Standard deviation versus normalized tip wear for four 3.18 mm drills.

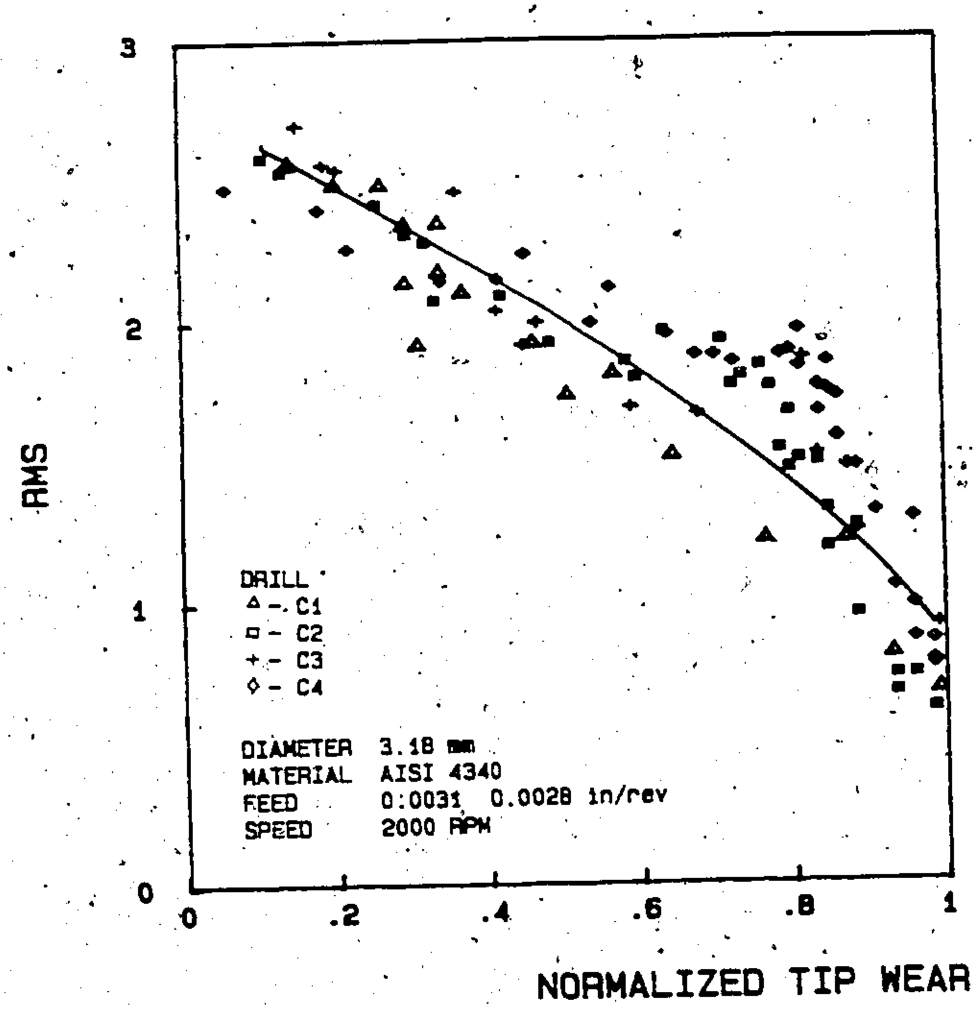


Figure 5.27 RMS of the distribution versus normalized tip wear for four 3.18 mm drills.

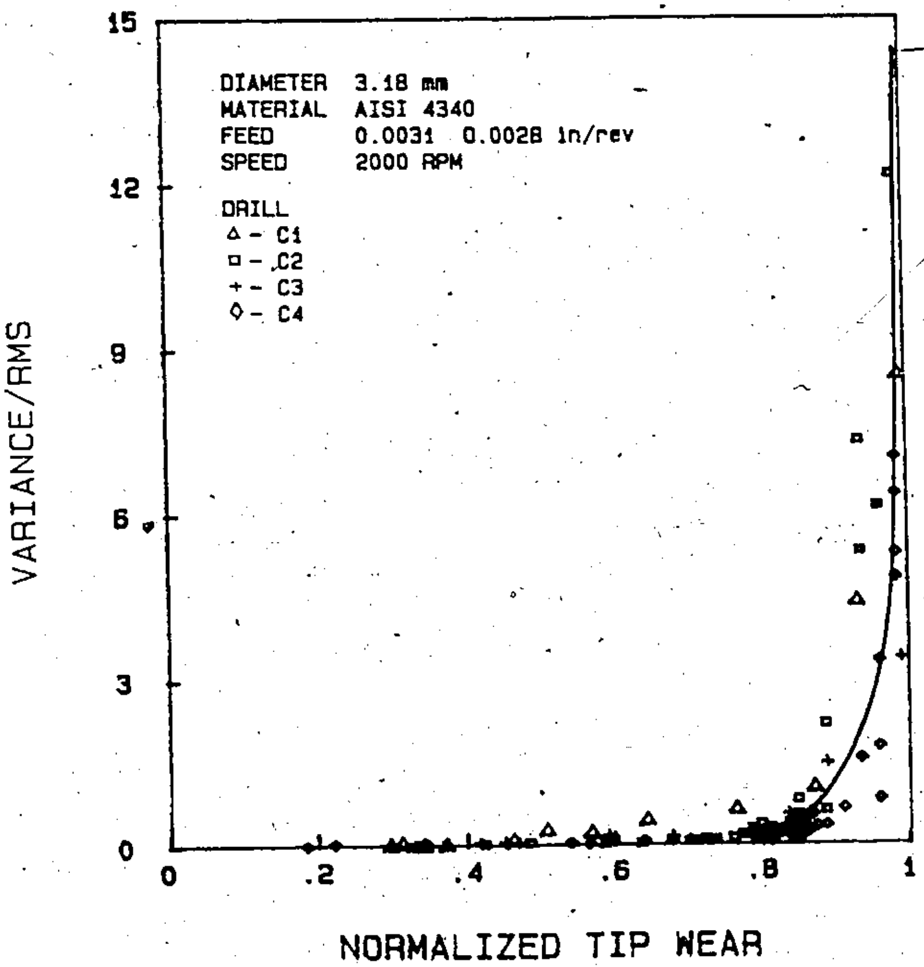


Figure 5.28 Variance/RMS versus normalized tip wear for four 3.18 mm drills.

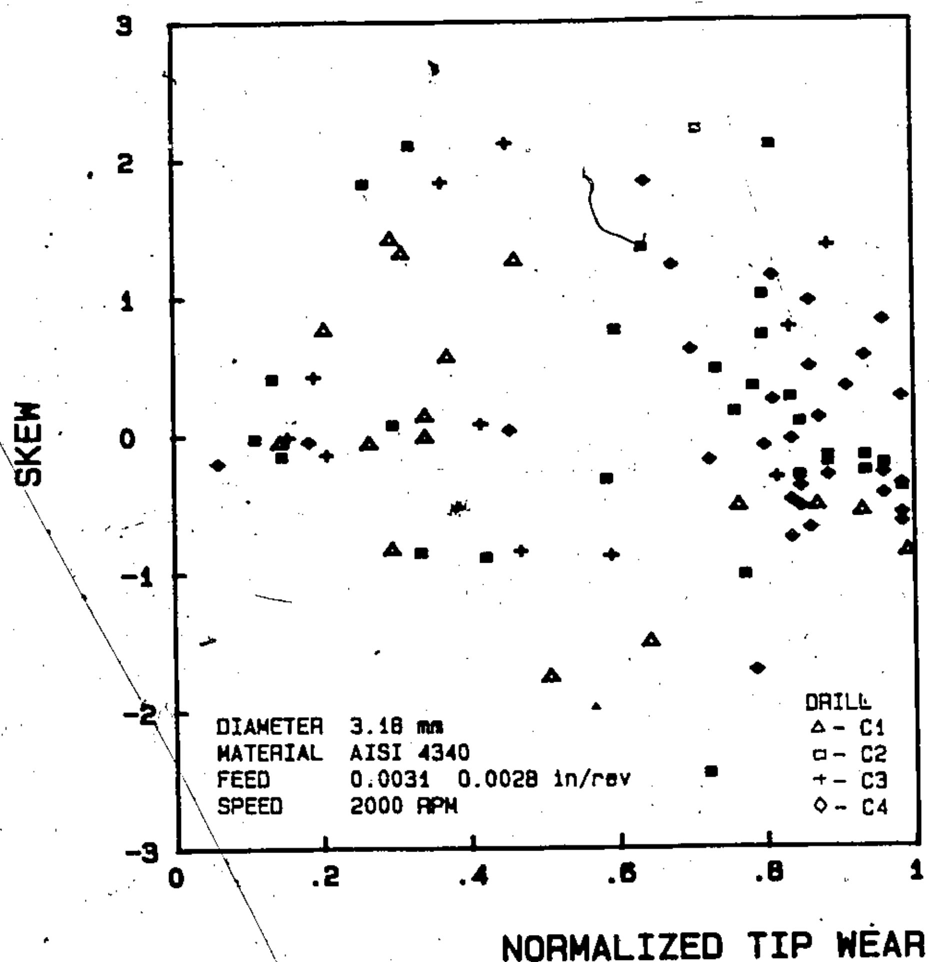


Figure 5.29 Skew versus normalized tip wear for four 3.18 mm drills.

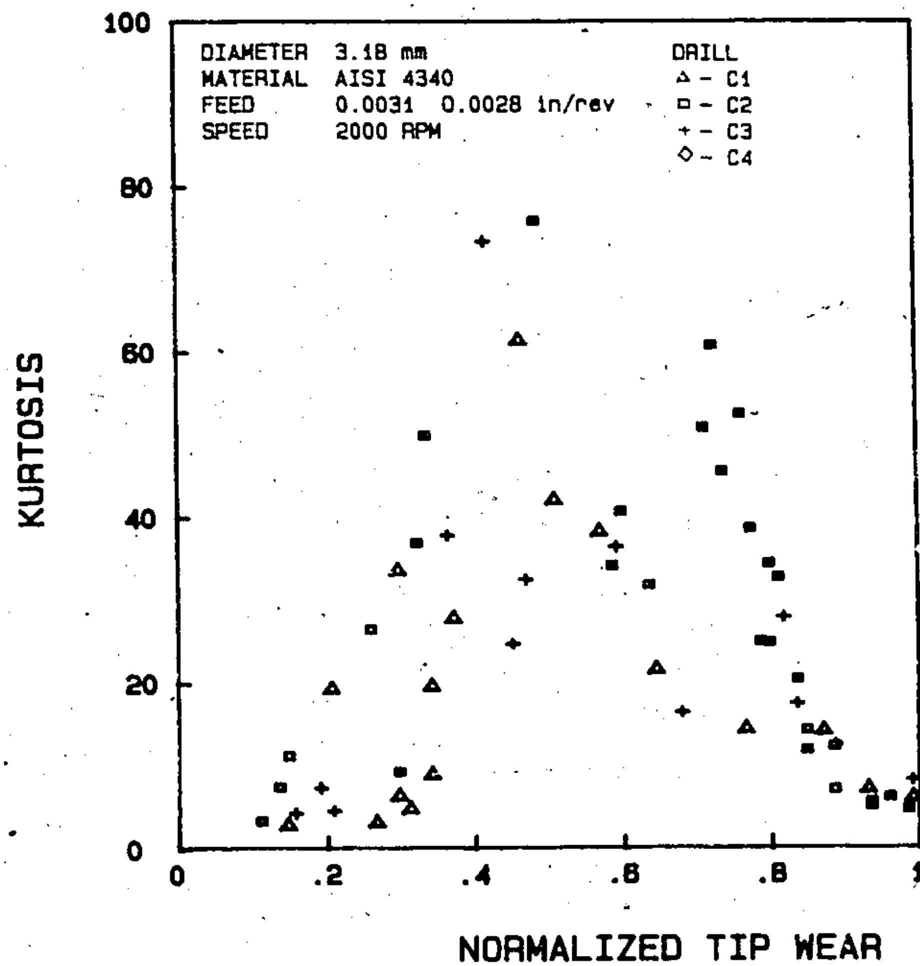


Figure 5.30 Kurtosis versus normalized tip wear for four 3.18 mm drills.

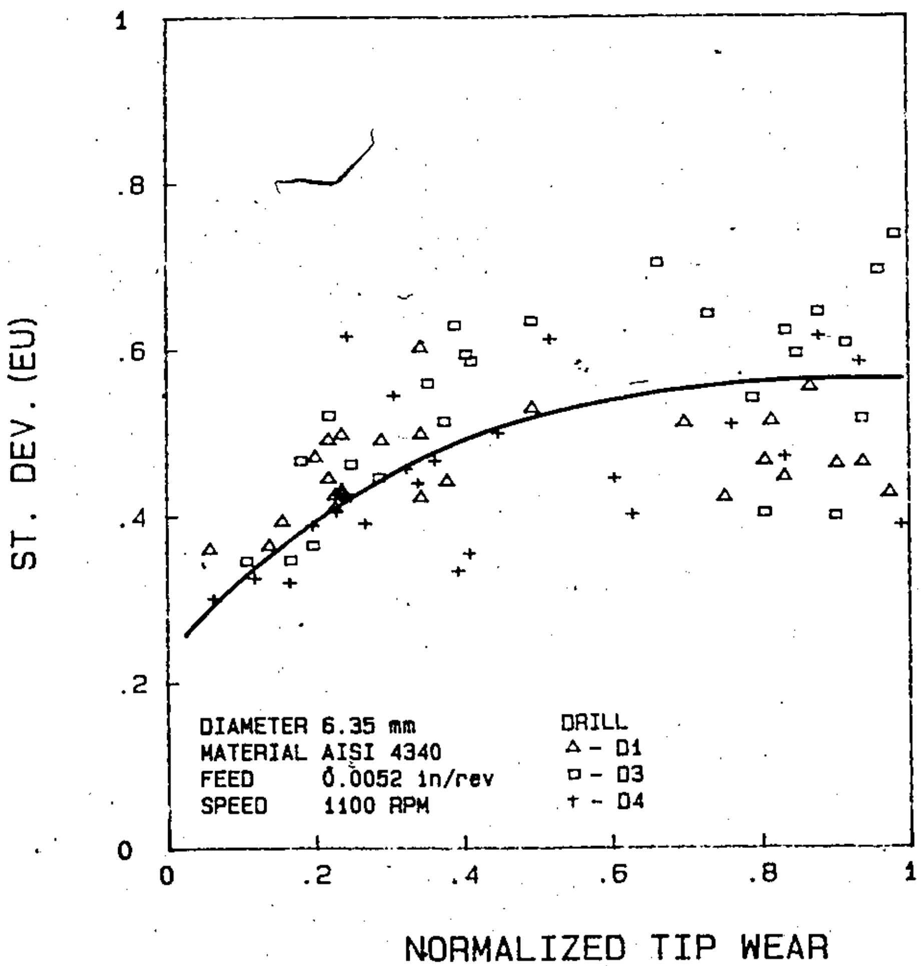


Figure 5.31 Standard deviation versus normalized tip wear for three 6.25 mm drills.

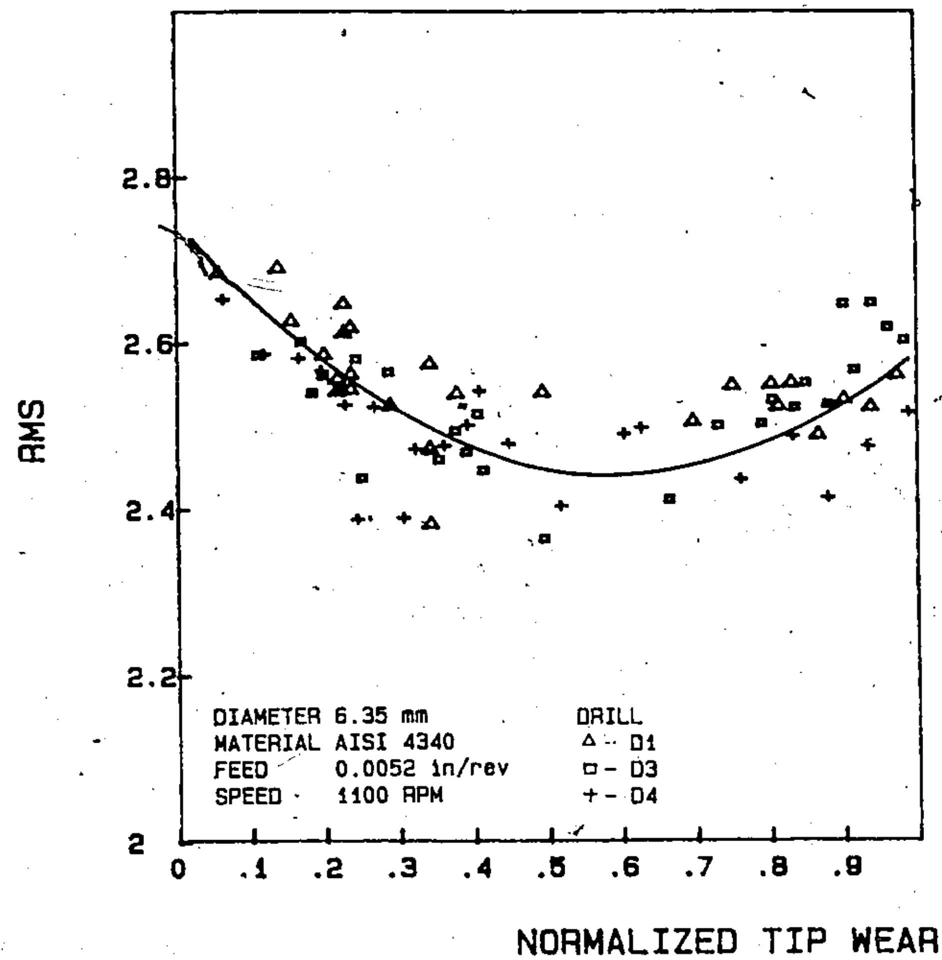


Figure 5.32 RMS of the distribution versus normalized tip wear for three 6.35 mm drills.

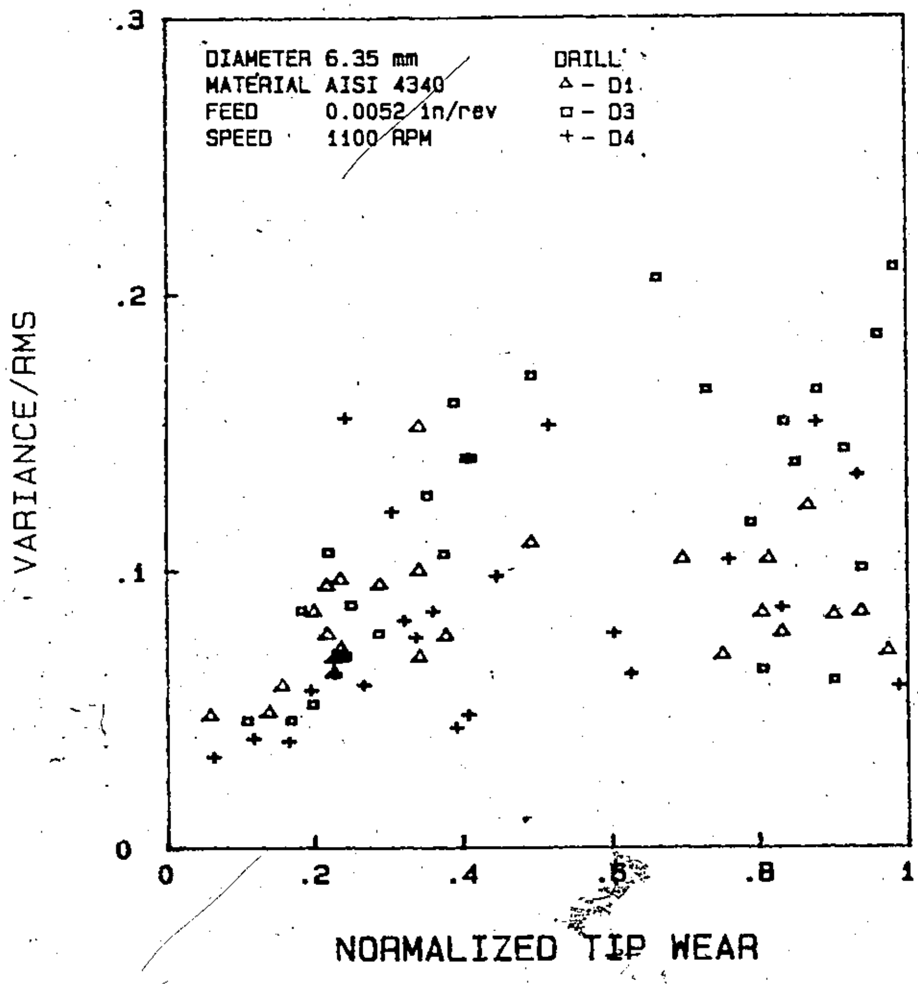


Figure 5.33 Variance/RMS versus normalized tip wear for three 6.35 mm drills.

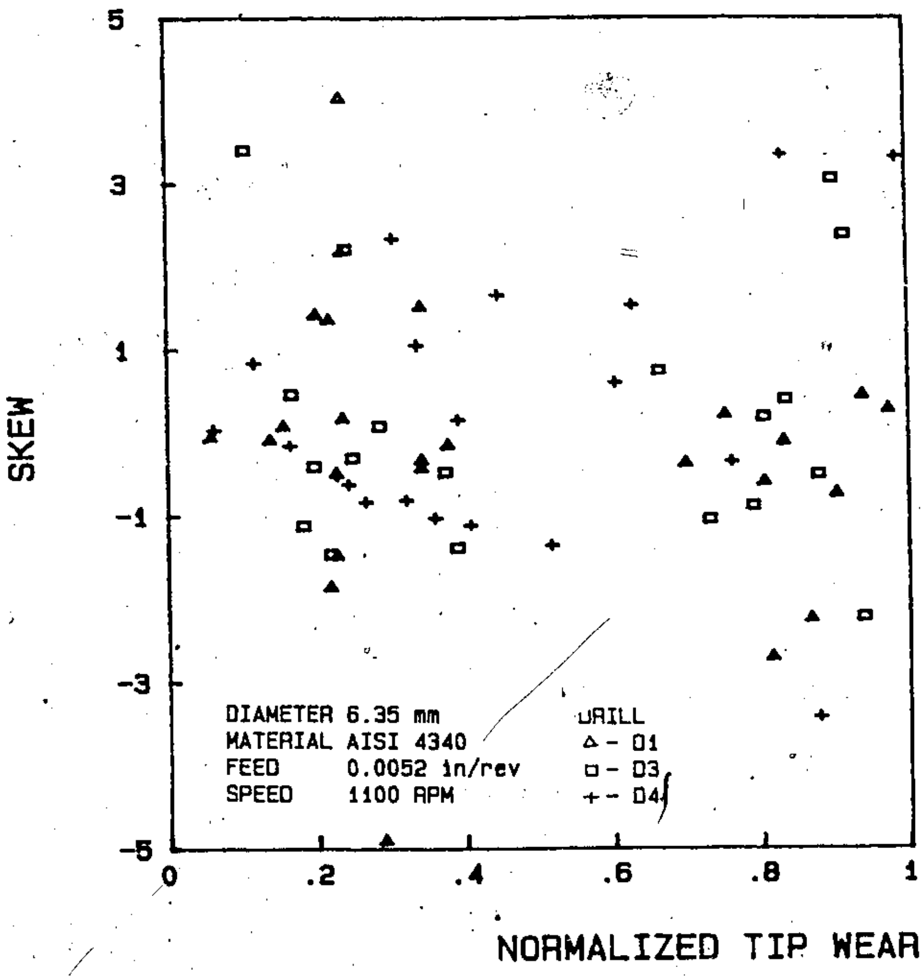


Figure 5.34 Skew versus normalized tip wear for three 6.35 mm drills.

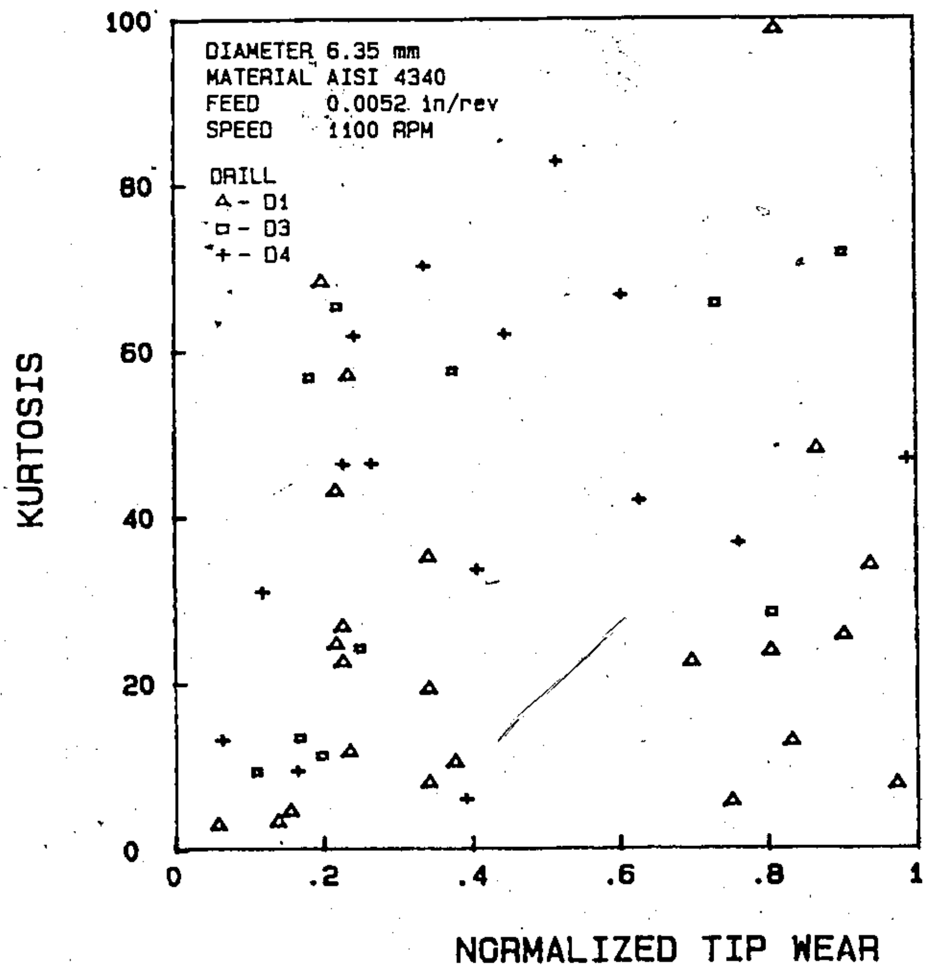


Figure 5.35 Kurtosis versus normalized tip wear for three 6.35 mm drills.

Chapter VI

CONCLUSIONS

The following conclusions have been reached after studying the results of the data analysis:

1). Statistical results for the 3.18 mm drill-size were better in comparison to those obtained from the 6.35 mm drill. This was predominantly due to the nature of the vibration signal obtained during the operation, i.e., more dense and spikes are more uniformly distributed for the smaller size.

2). The sampling rate which was used for digitizing has a significant influence only when the analog signals are spiky and with descriptors that exhibit a higher central moment about the mean, such as skew and kurtosis.

3). Mean values of the time-amplitude signal were found to be fairly constant at zero volts for both drill-sizes.

4). Plots of standard deviation versus percentage tip-wear for the 3.18 mm drill-size exhibited a very consistent trend with a very suitable shape for monitoring purposes. Only a weak increase in standard deviation was found with tip wear for 6.35 mm diameter drill bits.

5). The RMS of the frequency distribution is a more effective measure of the peakedness of the distribution than kurtosis. Again, for the 3.18 mm drill-size it did shown a good and consistent trend when plotted against the percentage tip-wear. The corresponding results for the 6.35 mm drills were far less useful.

6). Skew and kurtosis, generally, do not appear to be good descriptors for drill-wear monitoring, due to their random behaviour during a major portion of the drill-life. But they can be used as secondary descriptors for checking if tool failure is imminent because of their characteristic behaviour of convergence with wear. However, the author strongly feels that with a higher rate of sampling, ability to capturing more points, the effectiveness of these two descriptors will be improved. No correlation is evident between skew and kurtosis with tip wear for the 6.35 mm diameter drill bits.

7). The descriptor, variance/RMS significantly improves the sensitivity to tip wear, especially when failure is imminent, for 3.18 mm but not for 6.35 mm diameter drill bits.

Chapter VII

RECOMMENDATIONS

The use of vibration, with statistically evaluated descriptors, for tool-wear monitoring has great promise. However, there are still quite a number of areas that can be improved.

(1). The dynamic frequency range of the accelerometer-tape-recorder combination could have been higher instead of the 20 KHz.

(2). The A/D convertor used has a highest sampling rate of 20 KHz. A higher value is likely to improve results, particularly for larger diameter drills.

(3). A procedure using a larger number of points would improve the results.

(4). At present, only two drill-sizes were studied, namely 3.18 mm and 6.35 mm. In order to provide better basic information for monitoring system, the scope of the investigation should be extended to include:

(a). Different drill-size;

(b). Different drill and workpiece materials;

(c). Different drilling-machines;

REFERENCES

REFERENCES

1. Abou-Zeid, M.R., and Oweis, S.M.K., "Cutting Tool Wear". Microtecnic 1/1981, pp 42-47.

2. Acoustic and Vibration section, "The use of Vibration Data to detect tool breakage and wear", F. Jos Lamb Company Limited.

3. Amini, E., "Measurement of wear of Twist Drills"; Proc Instn Mech Engrs, Vol 195, 1981, pp 241-249.

4. Armarego, E.J.A., and Wright, J.D., "Predictive Models for Drilling Thrust and Torque - a comparison of three flank configurations", Annals CIRP, Vol 33/1/1984, pp 5-10.

5. Bandyopadhyay, B.P., "Experimental Determination of the Dynamic characteristics of metal cutting process", Machine Tool Desigh and Research, Vol 25, 1985, pp 241-244.

6. Ber, A., Nd Kaldor, S., " The first seconds of Cutting, Wear Behaviour", Annals CIRP, vol 31/1/1982, pp 13-17.

7. Bethea, R.M., Duran, B.S., and Boullion, T.L., Statistical Methods for Engineers and Scientists, second edition, Marcel Dekker, Inc., 1985.

8. Bhattacharyya, A., Chattopadhyay, A.B., and Roy, R., "Chisel-Edge Modification of Small HSS and Carbide Drills for improved Machinability", Annals CIRP, Vol 30/1/1981, pp 21-25.

9. Boston, O.W., and Gilbert, W.W., "The Torque and Thrust of small Drills operating in various metals", Trans. ASME, Vol 58, 1936, pp. 79-89.

10. Braun, S., Lenz, E., and Wu, C.L., " Signature Analysis Applied to Drilling", Trans. ASME, J. of Engg for Industry, Vol 104, April 1982, pp 268-275.

11. Brierley, R.G., and Siekmann, H.J., Machining Principles and Cost Control, McGraw Hill Company, 1964.

12. Burant, R.O., and Mcginty, M.J., "Cutting Tools/ Drills ", Manufacturing Engineering, Mar. 1979.

13. Chao, B.T., and Triger, K.J., "Temperature Distribution at Tool-chip and Tool-work Interface in Metal Cutting", Trans ASME, Vol 80, Feb. 1958, No 2, pp 311-320.

14. Devries, M.F., Saxena, U.K., and Wu, S.M., " Temperature Distributions in Drilling", Trans. ASME, Journal of Engg for Industry, May 1968, pp 231-237.

15. Dolodarenko, A.G., and Ham, I., "Effects of Built-up Edge in Drilling", Journal of Engg for Industry, Feb 1976, pp 287.

16. Dornfeld, D., "An Investigation of Orthogonal Cutting Via Acoustic Emission in Signal Analysis", Sixth North America Metal Working Research Conference, Univ. of Michigan, May 1979, pp 270-274.

17. Dornfeld, D., and Kannatey-Asibu, E., "Acoustic Emission During Orthogonal Metal Cutting", International Journal of Mech. science, Vol 2, No 5, 1980, pp 285-296.

18. Dornfeld, D.A., "Investigation of machining, and cutting tool wear and chatter using Acoustic Emission", 9th NSF Grantee's Conference on Production Research and Technology, Univ. of Michigan, Nov. 1981.

19. Drozda, T.J., and Wick, C., "Tool and Manufacturing Engineers Handbook, Vol 1 - Machining", Fourth Edition, Society of Manufacturing Engineers.

20. Ernst, H., and Haggerty, w.a., "The Spiral Point - A New Concept in Drill Point Geometry", Journal of Engineering for Industry, Trans. ASME.

21. Field, M., Zlatin, N., Williams, R., and Kronenberg, M., "Computerized Determination and Analysis of Cost and Production Rates for Machining Operation: Part 2-Milling, Drilling, Reaming, and Tapping", Trans. ASME, J. of Engg for Industry, Aug. 1969, pp 585-596.

22. Fuji, H., Marui, E., and Ema, S., "Whirling Vibration in Drilling. Part 1: Cause of Vibration and role of chisel Edge", Trans. ASME, journal of Engg for Industry, Aug., 1986, Vol 108, pp 157-162.

23. Fuji, H., Marui, E., and Ema, S., "Whirling Vibration in Drilling. Part 2: Influence of Drill Geometries, Particularly of the Drill Flank, on the Initiation of Vibration" Trans. ASME, journal of Engg for Industry, Aug., 1986, Vol 108, pp 163-168.

24. Fujii, S., Devries, M.F., and Wu, S.M., "An Analysis of Drill Geometry for Optimum Drill Design by Computer. Part 1-Drill Geometry Analysis", Trans. ASME, J. of Engg for Industry, Aug, 1970, pp 647-656.

25. Fujii, S., Devries, M.F., and Wu, S.M., "An Analysis of Drill Geometry for Optimum Drill Design by Computer. Part 2 Computer- Aided Design", Trans. ASME, J. of Engg for Industry, Aug, 1970, pp 657-666.

26. Galloway, D.F., "Some Experiments on the Influence of Various

Factors on Drill Performance", ASME Trans., Dec 9, 1955, pp 191-231.

27. Goldman, S., "Periodic Machinery monitoring: Do it right ?", Hydrocarbon Processing, August 1984.

28. Harris, D.O., and Dunegan, H.L, "Application of Acoustic Emission to Industrial Problems", Acoustic Emission-5, Non Destructive Testing, June 1974, pp 137-144.

29. Hovinga, H.J., "The Damage Caused by the Built-up Edge", Annals CIRP, Vol XVIV, PP 341-345.

30. Jetly, S., "Measuring Cutting Tool Wear on-line: Some Practical Considerations", Manufacturing Engg, July 1984, pp. 55-60.

31. Kaldor, S., and Lenz, E., "Drill Point Geometry and Optimization", Trans. ASME, J. of Engg for Industry, Vol 104, Feb. 1982, pp 84-90.

32. Kaldor, S., and Lenz, E., "Investigation in Tool Life of Twist Drills ", Annals CIRP, Vol 29/1/1980, pp 23-27.

33. Kaldor, S., Moore, K., and Hodgson, T., "Drill point designing by computer", annals of the CIRP, Vol 32/1/1983, pp 27-31.

34. Kanai, M., and Kanda, Y., "Statistical characteristics of Drill Wear and Drill Life for the standardized performance test", Annals of the CIRP, Vol 28/1/1979, pp 61.

35. Kenneth, W.Y., and Blomquist, D.S., " An on-line method of determining tool wear by time-domain analysis", SME Tech. Paper MR 82-901, 1982.

36. Kinnander, A., "Choice of Wear-Criteria in fully automated turning", Machine Tool Design and Research, Vol 2[illegible], 1981, pp 255-259.

37. Kramer, B.M., "A Comprehensive Tool Wear Model", Annals CIRP, vol 35/1/1986, pp 67-70.

38. kramer, B.M., and Suh, N.P., "Tool wear by solution: A quantitative understanding", Nov 1980, Vol 102, pp 303-309.

39. Lambe, C.G., Statistical Methods and Formulae, The English Universities Press Ltd, First Edition, 1967.

40. Lenz, E., Mayer, J.E., and Lee, D.G., " Investigation in Drilling", CIRP annals, Vol 27/1978, pp 35.

41. Levi, R., and Koch, U., "Some effects of the drill point shape

on the chisel edge contribution the cutting forces", Machine Tool Design and Research, Vol 13, 1972, pp 241.

42. Lindberg, B., and Lindstrom, B., "Measurements of the Segmentation Frequency in the Chip Formation Process", Annals CIRP, Vol 32/1/1983, pp 17-20.

43. Lorenz, G., "Helix Angle and Drill Performance", Annals CIRP, Vol 28/1/1979, pp 83.

44. Magrab, E.B., and Gilsinn, D.E., "Buckling Loads and Natural frequencies of Drill Bits and Fluted cutters", Trans. ASME, J. of Engg for Industry, Vol 106, Aug., 1984, pp 196-204.

45. Mayer, J.E., "Cutting Tool Monitoring", Commline, Nov.-Dec. 1985. pp 12-16,26-27.

46. Mckee, A., "Vibration Measurement can save million in downtine", Engg Digest, Feb 1987.

47. Nakayama, K., Shaw, M.C., and Brewer, R.C., "Relationship between Cutting Forces, Temperature, Built-up Edge and Surface finish", Annals CIRP, VOL XIV, pp 211-223.

48. Micheletti, G.F., Koenig, W., and Victor, H.R., "In-process Tool wear Sensors for cutting operation", Ann. of CIRP, v25/2, 1976, pp 483-496.

49. Moriwaki, T., "Sensing and Prediction of Cutting Tool Failure", Bull. Japan Soc. of Prec. Engg., Vol 18, No 2 (june 1984).

50. Neville, A.M., and Kennedy, J.B., Basic Statistical Methods for Engineers and Scientists, Intertext books, London, 1964.

51. Oxford, C.J., "On the Drilling of Metals, 1 - Basic Mechanics of the Process",Trans. ASME, Vol 77,Feb. 1955, P 1955.

52. Ogawa, M., "Effects of chip splitting Nicks in Drilling", CIRP, vol 34/1, 1985.

53. Parkinson, D., and Chahine, J., Drill Wear Monitoring using Vibration Signals in the Time Domain, Senior Project, Dept. of Mech. Engg, Univ. of Windsor, 1986.

54. Pandit, S.M., and Kashou, S.,"A Data Dependent systems strategy of on-line Tool Wear sensing", August 1982, Vol 104, pp 217-223.

55. Pandit, S.M.,"Application of DDS Dignostic Vibration Analysis", April 1980, Vol 102, pp 233.

56. Rabinowicz, E., Friction and Wear of Materials, John Wiley

and Sons, Inc., New York, 1964.

57. Renwick, J.T., and Babson P.E., "Vibration Analysis - A proven technique as a predictive maintenance tool", IEEE Trans. on industry Application, Vol 1A-21, Mar./April 1985, pp. 1059-1072.

58. Reif, Z., Private Communication, 1987.

59. saxena, U.K., Devries, M.F., and Wu, S.M., "Drill temperature distributions by Numerial Solutions", Trans. ASME, journal of Engg for Industry, Nov., 1971, pp 1057-1066.

60. Shaw, M.C., Metal Cutting Principle, Clarendon press, Oxford, 1984.

61. Shaw, M.C., and Oxford, C.J., "On The Drilling of Metals, 2 - The Torque and Thrust in Drilling", Trans. ASME, Vol 79, 1975, P139

62. Singpurwalla, N.D., and Kuebler, A.A., " A Quantitative Evaluation of Drill Life", ASME paper 66-WA/PROD-11.

63. Spur, I.G., and Masuha, J R., "Drilling with Twist Drills of Different cross section profiles", annals CIRP, Vol 30/1, 1981, P. 31-35 .

64. Smith, A., and McDowell, S., Tool wear Prediction through Spectral Analysis, Senior Project, Dept. of Mech. Engg, Univ. of Windsor, 1986.

65. Subramanian, K., and Cook, N.H., " Sensing of Drill Wear and Prediction of Drill Life", Trans. ASME, Journal of Engg for Industry, May 1977, pp 295-301.

66. Tagia, A.D., Portunato, S., and Toni, P., " An approach to On-line Measurement of Tool Wear by Spectrum Analysis", Machine Tool Design and Research, Vol 17, 1976, pp 141-148.

67. The Fundamentals of Signal Analysis, Application note 243, Hewlett Packard.

68. Thomsen, E.G., "Application of the Mechanics of Plastic Deformation to Metal Cutting", Annals CIRP., vol XIV, PP. 113-123.

69. Tirupathi, R., and William, D., "Effect of Drill Geometry on the Deformation of a Twist Drill", Machine Tool Design and Research, Vol 25, 1985, pp 231-235.

70. Turkovich, B.F., and Field, M., "Survey on Material Behaviour in Machining", Annals CIRP, Vol 30/2/1981, pp 533-536.

71. Venkatesh, V.C., "Tool Wear Investigations on Some Cutting

Tool Materals", Trans. ASME, Journal of Engg for Industry, Vol 102, Oct., 1980, pp 556-559.

72. Wall, F.J., Statistical Data Analysis Handbook, McGraw Hill Book Company, 1986.

73. Weatherburn, C.E., A First Course in Mathematical Statistic, Cambridge, 1961.

74. Welbourn, D.B., and Smith, J.D., Machine-Tool Dynamics : An Introduction, Cambridge, 1970.

75. Weller, E.J., "What Sound can be expected from a Worn Tool", Trans ASME, B, 91, 1969 , PP 525-534.

76. Wiriyacosol, S., and Armarego, E.J.A., "Thrust and Torque Prediction in Drilling from a Cutting Mechanics Approach", Annals CIRP, Vol 28/1/1979, pp 87-91.

77. Wright, P.K., and Bagghi, A., " Wear Mechanisms that Dominate Tool-life in Machining", J. Applied Metal Working, American Society For Metals, Vol 1, no. 4, pp 15-23.

78. Xistris, G.D., Boast, G.K., and Sankar, T.S., "Time Domain Analysis of Machinery Vibration Signals using Digital Techniques", Journal of Mech. Design, Vol 102, No 2, April 1980, pp 211.

APPENDIX A.

Statistical Results

DRILL #:A1
DRILL SIZE: 3.18 MM
HARRISON M400, SPEED=2000 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	4.094	0	.1568	-.127	6.359	2.848
2	15.11	0	.1752	-1.00	24.09	2.830
3	15.74	0	.2296	-4.07	100.5	2.773
4	19.21	0	.2895	3.474	60.01	2.530
5	20.15	0	.3190	1.823	45.97	2.571
6	21.10	0	.3106	2.058	39.49	2.555
7	22.99	0	.5204	.2966	92.85	2.429
8	23.30	0	.6061	-.289	54.36	2.344
9	27.08	0	.4175	-2.91	59.55	2.334
10	27.71	0	.4355	2.920	77.53	2.339
12	28.34	0	.5878	2.131	68.60	2.124
14	29.60	0	.6234	2.252	54.68	2.253
16	30.23	0	.7208	1.556	37.88	2.020
18	30.55	0	.6392	.6253	48.46	2.205
20	31.18	0	.7286	-.032	50.11	2.147
22	32.75	0	1.031	1.256	56.35	2.028
24	37.16	0	1.038	-.975	41.02	1.876
26	37.16	0	.5857	-2.33	73.72	2.239
30	37.48	0	.7295	.9227	22.63	1.831
32	38.11	0	.8997	.0720	16.94	1.674
34	38.11	0	1.165	-.073	13.57	1.512
36	40.31	0	.9946	-.811	18.45	1.614
37	40.31	0	1.214	-.359	19.26	1.510
38	42.2	0	1.076	.1126	10.26	1.505
39	45.66	0	1.154	.3703	13.11	1.584
40	49.76	0	1.376	-.366	14.14	1.425
41	52.59	0	1.387	.1568	10.58	1.362
42	53.85	0	1.673	-.483	9.290	1.194
43	54.48	0	1.591	.6917	11.17	1.254
44	56.06	0	1.729	.1950	7.285	1.225
45	57.32	0	2.026	-.047	8.473	1.237
46	58.89	0	1.969	.1800	6.935	1.045
47	59.52	.0106	2.674	.3218	7.247	.8832
48	60.15	0	3.197	.0968	4.915	.7234
49	60.47	0	2.940	.0975	4.770	.7297
50	60.78	0	3.329	.0856	4.907	.6912
51	60.78	.0130	4.166	5.068	4.787	.6394
52	61.10	0	3.605	.1328	4.567	.6494
53	61.10	0	3.137	.1197	5.483	.8286
54	61.10	0	3.317	.0397	4.510	.7272

DRILL #:A2
DRILL SIZE: 3.18 MM
HARRISON M400, SPEED=2000 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	19.21	0	.5624	-1.82	3.256	2.97
2	30.23	0	.6882	.2269	12.11	2.868
3	52.91	0	1.078	-1.09	22.22	2.583
4	60.15	0	1.724	1.753	57.13	2.483
5	61.10	0	2.948	.2187	9.530	1.674
6	62.67	0	4.889	-.350	13.12	1.308
7	63.93	0	4.898	-.158	6.634	1.222
8	68.66	0	6.255	-.190	7.696	1.096
9	68.66	0	7.32	-.686	6.8	1.039
10	68.66	0	6.738	-.329	5.08	1.083

DRILL #:A3
DRILL SIZE: 3.18 MM
HARRISON M400, SPEED=2000 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	5.669	0	.4892	.1665	3.121	3.191
2	40.31	0	.7133	-.431	14.06	2.9
3	41.57	0	.8633	-.547	29.73	2.84
4	51.33	0	.6005	.1708	5.113	2.926
5	53.22	0	.8657	-.226	54.20	2.923
6	54.80	0	.9342	.9034	37.79	2.808
7	55.11	0	1.123	1.390	64.31	2.761
8	56.69	0	1.412	5.630	168.3	2.656
9	59.21	0	1.763	.1599	43.87	2.508
10	59.21	0	1.548	-5.73	157.7	2.562
11	60.15	0	2.125	1.148	105.2	2.371
12	60.78	0	1.557	.4216	50.58	2.512
13	63.30	0	1.688	-3.91	67.18	2.513
14	64.25	0	1.340	-1.41	36.61	2.452
15	64.25	0	1.818	-4.91	106.7	2.537
16	65.82	0	2.415	1.163	108.5	2.379
17	66.14	0	1.919	-.326	47.79	2.308
18	67.08	0	2.691	-1.51	58.92	2.252
19	67.08	0	2.289	.7614	50.16	2.25
20	67.08	0	2.348	-1.32	42.27	2.298
21	67.08	0	2.307	.4419	34.46	2.206
22	67.08	0	2.093	-.948	30.27	2.18
23	67.40	0	2.121	-2.68	42.89	2.137
25	67.40	0	1.768	1.081	22.81	2.3
27.	67.40	0	3.387	.4139	11.24	1.621
28	67.40	0	3.724	.4453	10.62	1.475
29	68.03	0	5.733	-.242	9.462	1.117
30	68.03	0	5.694	.2363	6.716	1.124
31	68.03	0	5.935	.0216	8.199	1.111
32	68.03	0	5.989	8.776	7.976	1.129
33	68.34	0	5.306	.3482	7.639	1.193
34	68.66	0	6.125	-.148	8.705	1.141
35	68.66	0	6.292	.5314	9.216	1.082
36	68.97	0	5.818	-.480	8.57	1.147
37	68.97	0	6.211	-.256	9.087	1.183
38	69.29	0	5.789	-.442	8.936	1.128
39	69.60	0	7.805	-.806	7.526	.9835
40	69.92	0	7.708	.0905	5.844	.9906
41	70.23	0	8.461	.1020	6.016	.9443
42	70.55	0	9.110	.3586	6.158	.8895

DRILL #:A4
DRILL SIZE: 3.18 MM
HARRISON M400, SPEED=2000 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	7.244	0	.5628	-.010	3.230	2.983
2	7.559	0	.7389	-2.65	61.57	2.834
3	14.80	0	.6656	.0619	7.059	2.854
4	37.16	0	.7656	.3831	48.46	2.905
5	44.09	0	1.488	5.069	155.1	2.815
6	51.33	0	1.758	-2.68	65.60	2.597
7	53.85	0	2.150	-.541	29.93	2.317
8	57.32	0	3.761	.3949	7.756	1.428
9	57.95	0	3.760	.2092	6.473	1.363
10	58.58	0	4.526	-.019	6.514	1.205
11	60.47	0	3.845	-.387	6.376	1.36
12	61.10	0	4.643	-.201	5.742	1.213
13	61.41	0	5.115	-.164	5.617	1.128
14	61.73	0	4.631	.1853	6.844	1.248
15	61.73	0	5.120	-.099	5.933	1.148
16	62.04	0	4.770	-.114	6.180	1.191
17	62.04	0	4.850	.1113	6.966	1.257
18	62.36	0	8.891	.0430	6.469	.9215
19	62.67	0	6.106	.0125	5.236	1.023
20	64.25	0	5.523	.0149	5.577	1.107
21	64.88	0	9.164	-.066	5.236	.8635
22	65.51	0	9.510	.3305	5.922	.9534
23	66.14	0	11.19	-.474	7.389	.8556
24	66.77	0	9.231	.3777	5.671	.9203
25	67.71	0	9.295	.4152	4.983	.8576
26	68.03	0	9.587	.2866	5.817	.9169
27	68.34	0	8.512	.1374	5.761	1.008

DRILL #:B1
DRILL SIZE: 3.18 MM
COLHESTER MASTER 2500, SPEED=1860 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	8.818	0	.1742	-2.74	3.072	3.402
2	9.133	0	.1775	-.814	13	3.455
3	9.763	0	.1923	-.365	8.252	3.357
4	11.02	0	.1809	-9.91	3.517	3.373
5	11.65	0	.2046	.1977	7.986	3.187
6	15.11	0	.2015	-.046	3.761	3.196
7	15.43	0	.2017	.0539	4.495	3.229
8	16.06	0	.1918	-.1	3.846	3.303
9	16.37	0	.189	.1545	5.135	3.322
10	16.37	.0215	.2734	-.123	2.777	2.694
12	16.37	.0147	.3302	-.223	3.024	2.475
14	16.69	0	.3042	-.074	3.357	2.606
16	18.89	0	.3509	-.467	13.58	2.597
18	22.36	0	.6533	4.101	129.2	2.801
20	26.45	0	.99	-.973	88.5	2.322
22	31.49	0	1.315	.625	67.09	2.202
23	32.12	0	.8935	3.586	83.71	2.37
24	32.12	0	.4849	.756	94.77	2.576
25	32.44	0	.8922	-.835	101.2	2.556
26	32.44	0	1.036	.243	60.13	2.223
27	32.44	0	1.729	-1.17	45.41	2.078
28	33.07	0	1.184	-1.59	45.19	2.104
29	34.01	0	1.262	-2.56	41.55	1.864
30	34.33	0	1.55	1.26	32.99	1.718
31	35.9	0	1.727	-2.09	58.32	1.828
32	37.16	.0118	1.995	-.649	28.91	1.52
33	37.48	.0142	1.956	-.548	25.84	1.629
34	38.74	.0118	2.058	-.405	23.52	1.528
35	40	.0127	1.948	.5984	19.44	1.569
36	43.46	0	2.458	-.23	19.82	1.314
37	46.92	0	2.361	-.29	19.01	1.348
38	47.55	.0108	2.378	-.86	21.98	1.319
39	48.81	.0142	2.913	.0973	15.23	1.153
40	49.76	.0108	2.653	-.256	15.92	1.268
41	50.07	0	2.649	-.284	11.97	1.253
42	50.39	0	3.346	-.611	10.22	1.044
43	51.02	.0113	2.831	-.704	12.44	1.23
44	51.02	.0103	2.735	-.239	15.68	1.25
46	51.33	.0103	3.18	-.222	9.949	1.058
48	51.33	0	3.523	-.532	8.795	.9817
50	51.33	.0152	3.563	-.437	8.44	.9969
52	51.65	.0132	4.012	-.357	7.328	.8637
54	51.96	0	4.235	-.489	7.67	.8826
56	52.28	.0132	4.221	-.278	8.855	.8872
58	52.59	.0118	3.743	-.747	11.51	1.296

DRILL #:B2
DRILL SIZE: 3.18 MM
COLHESTER MASTER 2500, SPEED=1860 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	9.763	0	.1737	.1297	4.086	3.473
2	10.07	0	.3207	-2.2	74.73	3.111
3	10.39	0	.3081	-1.52	46.9	3.114
4	14.48	0	.4443	3.22	80.87	2.759
5	14.8	0	.3998	-5.01	114.1	2.936
6	17.32	0	.6095	2.422	213.9	2.94
7	22.04	0	1.072	4.122	96.13	2.52
8	22.99	0	1.325	-.327	69.23	2.281
9	23.3	0	1.364	-.866	49.58	2.305
10	26.45	0	1.429	-.479	35.24	2.143
12	26.77	0	1.121	-1.57	70.93	2.416
14	27.08	0	2.078	-1.2	42.04	1.963
16	29.29	0	2.782	.3669	19.08	1.649
18	31.81	0	2.748	-.599	20.54	1.637
20	34.33	0	2.91	-.551	18.13	1.626

DRILL #:B3
DRILL SIZE: 3.18 MM
COLHESTER MASTER 2500, SPEED=1860 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	4.094	0	.1875	.0103	4.034	3.325
2	4.409	0	.2121	1.928	32.5	3.306
3	5.354	0	.2777	-.492	36.24	3.18
4	5.669	0	.208	.2728	16.42	3.351
5	6.614	0	.1689	.0368	3.675	3.49
6	6.929	0	.2175	.7779	14.09	3.202
7	7.244	0	.293	.7711	37.53	3.103
8	11.02	0	.4646	3.008	137.7	2.804
9	18.58	0	.7458	8.104	219.3	2.784
10	23.93	0	1.119	2.534	91.3	2.727
12	26.14	0	1.954	-.866	31.63	2.049
13	26.77	0	1.694	-1.17	35.45	2.031
14	29.29	0	1.8	-.441	31.42	1.994
15	29.92	0	2.287	.9032	24.23	1.89
16	30.23	0	2.374	.0556	19.53	1.793
17	31.18	0	2.078	-.177	19.72	1.765
18	31.81	0	2.001	.2692	21.53	1.809
19	32.44	0	2.436	-.345	20.89	1.684
20	33.07	0	2.6	-.163	19.99	1.604

DRILL #:B4
DRILL SIZE: 3.18 MM
COLHESTER MASTER 2500, SPEED=1860 RPM, FEED=0.004 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	10.39	.0118	.3798	1.01	130.7	3.108
2	10.7	.0118	.6636	2.436	88.16	2.641
3	15.11	.0108	1.063	-1.88	98.75	2.604
4	21.1	.0127	2.152	.4567	29.94	1.795
5	21.73	.0108	2.14	1.02	28.07	1.704
6	21.73	.0132	2.404	.6872	18.96	1.602
7	23.62	.0103	2.848	.1678	15.44	1.431
8	24.25	0	2.568	-.437	15.65	1.254
9	26.45	0	3.025	-.618	12.13	1.112
10	28.03	0	3.053	-.189	10.91	1.071
11	30.23	0	3.111	-.283	12.71	1.074
12	36.53	0	3.89	-.507	9.132	.9144
13	42.83	0	4.556	-.063	7.75	.8395

DRILL #:C1
DRILL SIZE: 3.18 MM
OKUMA TYPE LS, SPEED=2000 RPM, FEED=0.0031 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	8	0	.1143	-.05	3.039	2.574
2	11.2	0	.1309	.7678	19.5	2.493
3	14.4	0	.1237	-.06	3.357	2.49
4	16	0	.2221	-.828	6.567	2.141
5	16	0	.1762	1.428	33.73	2.35
6	16.8	0	.3236	1.324	4.979	1.92
7	18.4	0	.1579	.1424	9.182	2.354
8	18.4	0	.2188	-.011	19.82	2.181
9	20	.0114	.2465	.5727	28	2.106
10	24.8	0	.4748	1.272	61.57	1.924
11	27.2	0	.7126	-1.75	42.2	1.738
12	30.4	0	.6709	-2.01	38.3	1.814
13	34.4	0	.8427	-1.5	21.71	1.521
14	40.8	.0172	.8975	-.518	14.53	1.222
15	46.4	0	1.134	-.518	14.34	1.22
16	49.6	0	1.893	-.561	7.324	.8113
17	52.8	0	2.409	-.858	6.228	.6819

DRILL #:C2
DRILL SIZE: 3.18 MM
OKUMA TYPE LS, SPEED=2000 RPM, FEED=0.0028 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	7.2	0	.1164	-.014	3.587	2.593
2	8.8	0	.1278	.4179	7.698	2.539
3	9.6	0	.1282	-.151	11.42	2.561
4	16.8	0	.1549	1.830	26.60	2.42
5	19.2	0	.1685	.0723	9.407	2.313
6	20.8	0	.1981	2.109	37.01	2.284
7	21.6	0	.3546	-.851	50.01	2.076
8	27.2	0	.3731	-.888	93.75	2.092
9	31.2	0	.4098	3.285	75.88	1.922
10	37.6	0	.3466	-.320	34.13	1.855
11	38.4	0	.4894	.7650	40.75	1.797
12	40.8	0	.3552	1.362	31.82	1.964
13	45.6	0	.4557	2.211	50.92	1.929
14	46.4	0	.50[illegible]	-2.45	60.94	1.768
15	47.2	0	.47[illegible]	.4750	45.57	1.802
16	48.8	0	.5258	.1588	52.62	1.838
17	49.6	0	.6122	-1.02	38.63	1.762
18	50.4	0	.7021	.3448	25.05	1.541
19	51.2	0	.7764	.7177	24.86	1.47
20	51.2	0	.6830	1.011	34.48	1.673
21	52	0	.7039	2.100	32.78	1.504
22	53.6	0	.7916	.2626	20.49	1.493
23	54.4	0	1.004	.0821	11.96	1.188
24	54.4	0	.8697	-.307	14.41	1.327
25	56.8	0	.9037	-.164	12.39	1.268
26	56.8	0	1.449	-.206	7.205	.9533
27	60	0	1.980	-.159	5.700	.7355
28	60	0	2.224	-.272	5.187	.6745
29	61.6	0	2.130	-.220	6.342	.7395
30	63.2	0	2.733	-.391	4.755	.6145

DRILL #:C5
DRILL SIZE: 3.18 MM
OKUMA TYPE LS, SPEED=2000 RPM, FEED=0.0036 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	6.4	0	.1233	-.082	3.289	2.491
2	12	0	.1913	.3054	48.54	2.341
3	24	0	.3499	-3.25	65.6	2.033
4	27.2	0	.4656	-4.84	113.1	1.904
5	32.8	0	.5882	-1.43	36.23	1.815
6	37.6	0	.7376	-2.02	29.05	1.641
7	39.2	0	.7777	-2.22	38.8	1.733
8	40	0	.8313	-2.79	39.1	1.672
9	41.6	0	1.05	-1.09	19.44	1.371
10	46.4	0	1.242	-1.77	17.98	1.319
11	51.2	0	1.101	-1.58	19.76	1.36

DRILL #:C6
DRILL SIZE: 3.18 MM
OKUMA TYPE LS, SPEED=2000 RPM, FEED=0.0031 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	12	0	.1275	-.102	4.695	2.549
2	17.6	0	.1324	.0249	3.331	2.477
3	20	0	.167	-1.95	43.28	2.303
4	27.2	0	.4237	-4.36	110.8	1.969
5	33.6	0	.767	-1.07	27.35	1.657
6	40	0	1.024	-.732	24.33	1.519
8	45.6	0	1.106	-1.26	20.85	1.347
9	46.4	0	1.134	-.249	18.73	1.339
10	48	0	1.442	.1104	13.1	1.113
11	49.6	0	1.989	-.715	7.591	.803

DRILL #:C7
DRILL SIZE: 3.18 MM
OKUMA TYPE LS, SPEED=2000 RPM, FEED=0.0031 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	3.2	0	.1225	.0557	3.326	2.474
2	8	0	.2172	.3900	26.79	2.11
3	11.2	0	.3138	-.476	38.64	1.881
4	19.2	0	.2815	.8425	22.92	1.99
5	20.8	0	.3594	.5560	23.25	1.895
6	25.6	0	.4718	-.891	28.80	1.714
7	27.2	0	.4881	-1.06	37.91	1.848
8	28	0	.4302	-1.91	53.92	1.813
9	28	0	.4489	-.364	32.79	1.686
10	29.6	0	.4338	-1.38	25.65	1.842
11	32	0	.6535	-.483	17.99	1.526
12	36	0	1.039	-.936	18.83	1.414
13	43.2	0	1.106	-.701	14.36	1.298
14	50.4	0	1.360	-1.02	11.91	1.128
15	57.60	0	1.529	-.857	12.52	1.135

DRILL #:D1
DRILL SIZE: 6.35 MM
OKUMA TYPE LS, SPEED=1100 RPM, FEED=0.0052 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	2.8	0	.3601	-.055	3.115	2.685
2	6.4	0	.3646	-.083	3.511	2.691
3	7.2	0	.3940	.0795	4.795	2.627
4	9.2	0	.4714	1.429	68.45	2.586
5	10	0	.4921	1.361	24.81	2.543
6	10	0	.4454	-1.85	43.33	2.557
7	10.4	0	.4251	-1.47	26.94	2.614
8	10.4	0	.4105	-.479	22.69	2.649
9	10.8	0	.4264	2.194	57.21	2.620
10	10.8	0	.4312	.1732	11.94	2.563
11	10.8	0	.4985	4.041	136.5	2.545
14	13.2	0	.4914	-4.90	131.8	2.525
15	15.6	0	.4989	1.526	35.38	2.474
18	15.6	0	.6030	-.419	19.51	2.383
20	15.6	0	.4224	-.322	8.231	2.576
22	17.2	0	.4424	-.139	10.74	2.540
24	22.4	0	.5298	-5.16	106.1	2.541
26	31.6	0	.5115	-.369	22.72	2.506
27	34	0	.4217	.2198	5.845	2.550
28	36.4	0	.4659	-.593	23.99	2.551
29	36.8	0	.5137	-2.70	98.87	2.525
30	37.6	0	.4462	-.097	13.09	2.553
31	39.2	0	.5549	-2.24	48.27	2.490
32	40.8	0	.4618	-.731	25.81	2.533
33	42.4	0	.4639	.4515	34.29	2.524
34	44	0	.4267	.2774	7.961	2.563

DRILL #:D2
DRILL SIZE: 6.35 MM
OKUMA TYPE LS, SPEED=1100 RPM, FEED=0.0052 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	3.6	0	.3687	-3.78	3.747	2.673
2	5.6	0	.3766	.4407	9.569	2.691
3	8.4	0	.4132	.2486	13.94	2.659
4	12.4	0	.4779	-1.08	50.38	2.597
5	15.2	0	.4265	2.718	70.15	2.670
6	16.8	0	.4770	4.341	85.43	2.595
7	19.2	0	.4171	.8055	12.56	2.591
8	19.2	0	.5170	.7274	69.30	2.553
9	19.6	0	.4276	.3012	8.879	2.594
10	19.6	0	.5500	5.703	127.2	2.535
11	19.6	0	.6223	-.624	72.25	2.540
14	24.8	0	.7787	-1.24	42.58	2.463
16	27.2	0	.7003	2.084	64.40	2.508
18	32.8	0	1.065	.3217	40.82	2.305
20	40	0	.7895	1.988	126.0	2.420
21	41.2	0	.6056	.4158	62.36	2.465
22	42.4	0	2.476	-.012	47.96	2.027

DRILL #:D3
DRILL SIZE: 6.35 MM
OKUMA TYPE LS, SPEED=1100 RPM, FEED=0.0052 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	6.[illegible]	0	.3466	3.405	9.548	2.586
2	9.2	0	.3480	.4633	13.63	2.603
3	10	0	.4679	-1.11	56.93	2.540
4	10.8	0	.3653	-.392	11.35	2.562
5	12	0	.5219	-1.45	65.46	2.544
6	13.2	0	.4229	2.224	104.7	2.582
7	13.6	0	.4634	-.297	24.25	2.438
8	15.6	0	.4467	.0905	87.99	2.566
9	19.2	0	.5604	-8.81	264.3	2.460
10	20.4	0	.5147	-.468	57.63	2.496
11	21.2	0	.6306	-1.37	339.5	2.469
12	22	0	.5951	-5.13	138.0	2.516
13	22.4	0	.5867	-3.63	103.6	2.447
14	26.8	0	.6352	5.141	282.1	2.364
15	36	0	.7045	.7532	101.4	2.412
16	39.6	0	.6429	-1.04	65.79	2.502
17	42.8	0	.5416	-.875	136.0	2.504
18	43.6	0	.4035	.1986	28.50	2.533
19	45.2	0	.6233	.4104	264.8	2.523
20	46	0	.5956	-14.8	641.7	2.553
21	47.6	0	.6462	-.501	223.1	2.527
22	48.8	0	.4000	3.067	71.87	2.648
23	49.6	0	.6082	2.390	158.1	2.568
24	50.8	0	.5170	-2.21	345.9	2.650
25	52	0	.6964	-9.29	306.3	2.619
26	53.2	0	.7387	7.939	257.7	2.603

DRILL #:D4
DRILL SIZE: 6.35 MM
OKUMA TYPE LS, SPEED=1100 RPM, FEED=0.0052 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	3.2	0	.3006	.0326	13.31	2.735
2	6	0	.3241	.8349	31.00	2.660
3	8.4	0	.3189	-.168	9.455	2.653
4	10	0	.3873	-5.24	117.3	2.636
5	11.6	0	.4042	-.534	46.40	2.590
6	12.4	0	.6147	-.633	61.79	2.435
7	13.6	0	.3894	-.844	46.37	2.588
8	15.6	0	.5436	2.334	86.66	2.437
9	16.4	0	.4548	-.823	193.3	2.531
10	17.2	0	.4375	1.047	70.11	2.529
11	18.4	0	.4650	-1.04	93.01	2.536
12	20	0	.3323	.1497	6.040	2.564
13	20.8	0	.3531	-1.12	33.65	2.610
14	22.8	0	.4985	1.648	61.97	2.538
15	26.4	0	.6112	-1.37	82.73	2.453
16	30.8	0	.4436	.5906	66.52	2.552
17	32	0	.3996	1.521	41.86	2.560
18	38.8	0	.5079	-.367	36.70	2.489
19	42.4	0	.4688	3.335	177.0	2.549
20	44.8	0	.6145	-3.44	106.2	2.464
21	47.6	0	.5829	6.658	269.4	2.535
22	50.4	0	.3863	3.303	46.85	2.581

DRILL #:E1
DRILL SIZE: 6.35 MM
HARRISON M400, SPEED=1000 RPM, FEED=0.005 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	3.149	0	.7058	-.555	48.75	2.033
2	6.929	0	.7087	-3.92	166.8	2.089
3	10.23	0	.6054	-2.14	52.96	1.998
4	11.81	0	.8443	-2.77	97.59	1.858
5	12.44	0	.8884	-1.01	61.16	1.776
6	12.59	0	.8502	.5216	32.23	1.675
7	13.07	0	.7390	-.323	159.2	2.113
8	13.54	0	.8728	-2.63	77.47	1.778
9	14.80	0	.9146	-1.20	99.93	1.702
10	16.53	0	.9853	.1994	31.70	1.783
12	18.11	0	.8595	.7450	148.6	2.003
14	21.41	0	1.239	.0412	59.91	1.650
16	22.51	0	1.141	-1.23	82.14	1.856
18	23.30	0	1.180	-.954	46.35	1.628
20	25.98	0	1.132	-1.79	65.67	1.796
22	28.97	0	.6984	2.708	76.37	2.047
24	29.13	0	.9486	2.125	81.20	1.812
26	30.07	.0119	1.183	.9741	84.56	1.834
28	31.65	.0115	1.152	-2.54	91.01	1.828
30	38.42	.0115	1.330	.0685	68.13	1.762
32	40	.0129	1.284	1.015	72.71	1.813
34	42.20	0	1.454	-.997	69.41	1.747
36	42.67	.0100	1.315	-2.42	81.34	2.105
38	43.14	.0121	2.534	-.077	26.24	1.674

DRILL #:E2
DRILL SIZE: 6.35 MM
HARRISON M400, SPEED=1000 RPM, FEED=0.005 IN/REV

HOLE#	% WEAR	MEAN	ST. DEV.	SKEW	KURTOSIS	RMS
1	4.094	0	.3143	-.427	13.14	2.340
2	4.409	0	.5656	-.133	39.47	1.909
3	4.724	0	.8733	-.059	38.93	1.709
4	5.984	0	.8832	-1.91	59.36	1.788
5	7.086	0	.7502	-1.46	119.5	1.983
6	7.401	0	.9786	.3003	35.24	1.653
7	7.559	0	1.148	-.906	47.96	1.563
8	8.031	0	1.155	.3066	41.76	1.596
9	10.86	0	.9987	-2.51	46.20	1.594
10	11.02	0	.9982	-.577	88.55	1.820
12	11.02	0	1.172	.4120	25.03	1.540
14	11.96	0	1.221	-.140	59.51	1.694
16	12.59	0	1.722	.1246	34.01	1.503
19	12.59	0	1.225	.9963	77.26	1.780
20	13.07	0	1.186	.8116	41.88	1.518
22	13.85	0	1.392	.1269	51.78	1.564
24	15.59	0	1.762	-.868	32.77	1.450
26	18.58	0	1.545	.1625	31.07	1.482
28	21.10	0	1.379	.1570	48.83	1.673
30	24.72	0	1.199	.0958	83.88	1.816
32	26.92	0	1.192	.7776	65.57	1.628
34	27.87	0	1.834	-.179	36.76	1.437
36	30.55	0	1.341	-3.20	70.96	1.834
38	33.54	0	1.730	9.409	41.67	1.397
39	34.48	0	1.620	-.083	59.34	1.893
40	36.37	0	1.380	-.805	72.36	1.832
41	37.16	0	1.273	-1.89	82.74	1.987
42	38.58	0	1.218	-.013	97.59	1.877
43	40	0	2.160	.1471	34.16	1.583

Appendix B.

AI13 A/D Converter

AI13 A/D Converter

The AI13 Analog Input System is a high-performance 12-bit data acquisition system for the Apple II computer. It plugs directly into one of the expansion slots and gives the Apple the ability to make precision voltage measurements.

With the AI13, any instrument or sensor producing an electrical signal becomes an Apple II input device. Software selects the input range, so sensor output ranges from 5 volts down to 0-100 millivolts can be accomodated. The operation process is fast, allowing acquisition of DC through audio frequencies.

It is designed to make voltage readings and return a number proportional to the result for analysis by a program. It can select one of the 16 input channels, scale the input according to any of the 8 full-scale ranges, and return the result in less than 20 microseconds. Table B.1 gives all the AI13 performance specifications.

When a conversion is requested by the program, the desired analog signal is selected by a 16 channel multiplexer. The signal is sampled for a 6 microseconds interval, then held constant by a sample and hold amplifer. The conversion process consists of twelve 1-microsecond successive approximation steps, a binary search for the value of the unknown input signal. The converter first tests the signal to determine if it is in the upper or the lower half of the range. This determines the most significant bit. Next a test is made to determine which quarter within the half contains the signal value, then which eighth within that quarter, etc. The most significant four bits are completed after a total of 11 microseconds including hole and conversion time. In high speed applications, the program may actually read these four bits before the entire conversion is completed and thus "overlap" the read and convert functions. The complete 12-bit result is ready after 19 microseconds. figure B.1 shows schematically how this conversion process is done by AI13 A/D converter.

Modification of one of the five programs, namely GETAI13 available on the demostration diskette is needed in order to suit the needs of this project. GETAI13 is a utility subroutine which rapidly makes a list of analog readings and returns the results to an Aplesoft program. The sampling rate during a call to GETAI13 is approximately 20,000 samples per second.

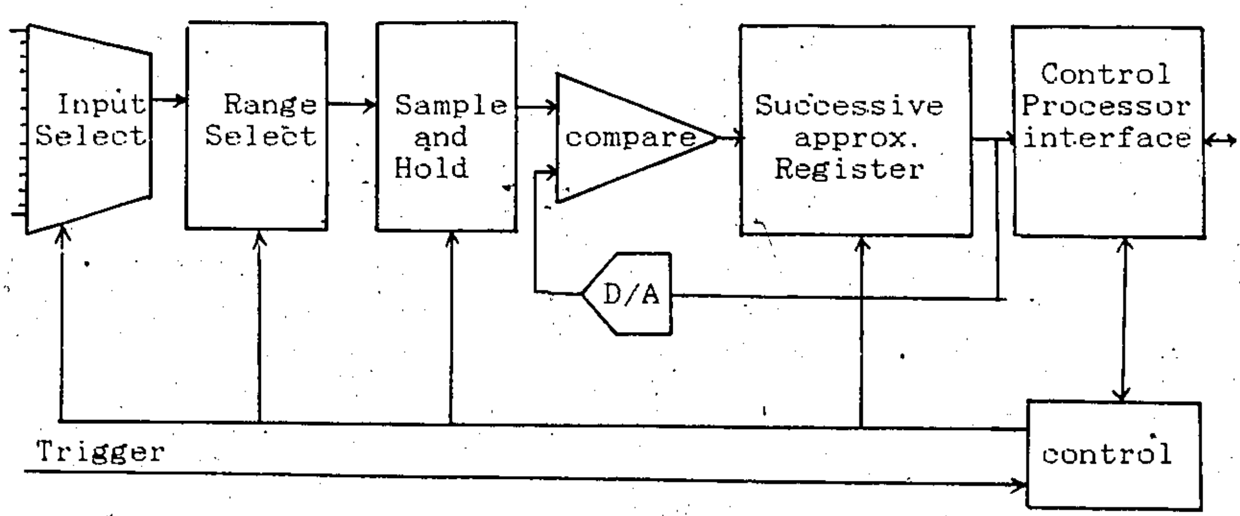


Figure B.1 The schematic diagram of the A/D process in AI13.

Input Full-scale Ranges (volts)

GAIN CODE	SIZE OF RANGE
Ø	Ø TO 5.Ø
1	Ø TO 1.Ø
2	Ø TO Ø.5
3	Ø TO Ø.1
4	-5.Ø TO +5.Ø
5	-1.Ø TO +1.Ø
6	-Ø.5 TO +Ø.5
7	-Ø.1 TO +Ø.1

Input Impedance : 1Ø MegaOhms

Input Protection : Input can withstand 22 volts.

Resolution : 12 Bits, 4Ø96 steps.

Coding : Binary, Ø to 4Ø95 full-scale.
Ø is min. 4Ø95 is max. value.

Overrange Processing : Values greater Max. will appear as 4Ø95.
Values less than Min. appear as Ø.

Deviation from ideal step size : Ø.Ø24 % maximum.

Selection and Sampling : 6 microseconds.

Hold and Conversion : 13 microseconds.

Total Conversion time : 2Ø microseconds.

Sampling Aperture : 125 nanoseconds.

Table B.1. AI13 Performance Specifications

APPENDIX C.

Computer programs

COMPUTER PROGRAMS

Computer programs are a very essential part of this research project as a large quantity of data have to be captured, processed, and presented. As mentioned previously, three user-friendly computer programs, written in Applesoft basic were developed, each serves its unique purpose of data capturing (Data acquisition program), data processing (Statistical analysis program), and data presentation (Plotting and curve-fitting program). The related accessories used are:

1. DUMPLING-GX parallel printer interface-card.
2. EPSON SPECTRUM LX-80 Printer.
3. IEEE-488 INTERFACE CARD.
4. HP 7475A GRAPHICS PLOTTER.
5. AI13 A/D CONVERTER.

The listing for the three programs are included in the next few pages.

C.1. DATA ACQUISITION PROGRAM.

```
10  HOME : VTAB 10: PRINT  TAB( 12);"WAIT......."
20  REM    ***********************************
30  REM    *  DATA ACQUISITION PROGRAM        *
32  REM    *  ----------------------          *
40  REM    *  1. ACQUIRE DATA USING AI13      *
50  REM    *  2. STORE RAW/DIGITIZED DATA     *
60  REM    *  3. GROUP RAW DATA               *
70  REM    *  4. STORE GROUPED DATA           *
80  REM    ***********************************
90  PRINT  CHR$ (4);"BLOAD GETAI13.DELAY,A$9000"
92  TEXT : HOME : VTAB 2: HTAB 10: PRINT "DATA ACQUISITION"
93  HTAB 10: FOR I = 1 TO 16: PRINT "-";: NEXT
100  DIM A%(1,4000),SDR%(260),X%(260),Y%(260)
110  REM    ***********************************
120  REM    *        SET-UP FOR A/D            *
121  REM    *        -------------             *
130  REM    *     D = SAMPLE INTERVAL DELAY    *
140  REM    *    GC = GAIN CODE/INPUT          *
150  REM    *         SIGNAL RANGE             *
160  REM    *   PTS = # OF DIGITIZED DATA      *
170  REM    ***********************************
180  PRINT : PRINT
182  HTAB 8: INPUT "NUMBER OF DIGITIZED DATA :";PTS
190  HTAB 8: INPUT "ENTER DELAY VALUE: ";D
200  POKE 25,D
210  A%(0,0) = 5:A%(1,0) =  - PTS
220  HTAB 8: INPUT "GAIN CODE :";GC:DD = 1 + GC * 16
230  PRINT : PRINT  TAB( 8);"WAIT...SET UP CHANNEL"
240  FOR I = 1 TO PTS:A%(0,I) = DD: NEXT I
250  VTAB 23: HTAB 8: PRINT "PRESS ANY KEY TO ";: INVERSE : PRINT "CAPTUR
     E SIGNAL": NORMAL : GET Z$
260  REM   ****  CAPTURE DATA  ****
270  POKE 8,1: CALL 36864
280  VTAB 23: HTAB 1: CALL - 868
290  VTAB 12: PRINT  TAB( 10);"1. STORE DATA ?": PRINT  TAB( 10);"2. DISP
     LAY DATA ?": PRINT  TAB( 10);"3. GROUPING ?"
292  PRINT  TAB( 10);"4. ANOTHER SIGNAL ?": PRINT  TAB( 10);"5. EXIT ?"
300  VTAB 19: HTAB 10: INPUT "SELECTION (1-5):";AN$
302  IF  VAL (AN$) < 1 OR  VAL (AN$) > 5 THEN  CALL  - 868: GOTO 300
310  IF AN$ = "2" THEN  FOR I = 1 TO PTS: PRINT  TAB( 10);I; TAB( 20);A%(
     1,I): NEXT I: GET Z$: HOME : GOTO 290
320  IF AN$ = "3" THEN 490
321  IF AN$ = "1" THEN 340
322  IF AN$ = "4" THEN  HOME : GOTO 1070
324  IF AN$ = "5" THEN  END
340  REM  ****  STORE RAW DATA   ****
350  PRINT :: INPUT "HOLE # :";HOLE[illegible]
360  INPUT "FILENAME :";NAME$[illegible]
370  INPUT "DRIVE(D1/D2) ?";D[illegible]
380  INPUT "SATISFY (Y/N) ?";[illegible]
390  IF AN$ = "N" THEN 350
400  PRINT  CHR$ (4);"OPEN";NAM[illegible] + "," + DR$
410  PRINT  CHR$ (4);"WRITE";NAME$
```

```
420 PRINT HOLE: PRINT PTS
430 FOR KK = 1 TO PTS
440 PRINT A%(1,KK): NEXT KK
450 PRINT CHR$ (4);"CLOSE"
452 GOTO 290
460 REM
490 HOME : VTAB 3: HTAB 8: PRINT "GROUPING RAW DATA": PRINT
500 VTAB 5: HTAB 8: PRINT "# OF DIVISION/CLASS :";DIV
510 VTAB 7: HTAB 8: INPUT "SATISFY (Y/N) ?";AN$: PRINT
520 IF AN$ = "Y" THEN 700
530 IF AN$ < > "N" THEN 510
540 HTAB 8: INPUT "NUMBER OF DIVISION ";DIV
570 REM    **********************************
580 REM    *  ... GROUPING ROUTINE ...      *
590 REM    *  SDR%(I) = CLASS BOUNDARY      *
600 REM    *  X%(I) = CLASS MID-POINT       *
610 REM    *  Y%(I) = CLASS FREQUENCY       *
620 REM    **********************************
630 RANGE = 4096
640 INC = RANGE / DIV
650 SDR%(0) = 0
660 FOR I = 1 TO DIV
670 SDR%(I) = I * INC
680 X%(I) = (SDR%(I) + SDR%(I - 1)) / 2
690 NEXT I
700 HOME : HTAB 8: PRINT "WAIT... GROUPING ";PTS
710 FOR I = 1 TO PTS
720 RRNT = INT (A%(1,I) / INC)
730 Y%(RRNT + 1) = Y%(RRNT + 1) + 1
740 NEXT I
750 HOME : VTAB 10: HTAB 10: PRINT "END...GROUPING"
760 PRINT : VTAB 15: HTAB 10: PRINT "1). STORE STATS DATA ?": PRINT TAB(
    10);"2). PRINT STATS DATA ?": PRINT TAB( 10);"3). CONTINUE ?": PRINT
    : HTAB 10: INPUT "SELECTION (1/2/3) :";AN
770 IF AN < 1 OR AN > 3 THEN 760
780 IF AN = 2 THEN 980
790 IF AN = 3 THEN 1030
800 IF AN = 1 THEN 810
802 REM    **** STORE GROUPED DATA ****
810 INPUT "HOLE #:";HOLE
820 INPUT "FILENAME STORE(SD) ?";NAME$
830 INPUT "DRIVE (D1/D2) ?";DR$
840 VTAB 12: INPUT "SATISFY (Y/N) ?";AN$
850 IF AN$ = "N" THEN 810
860 VTAB 15: HTAB 10: PRINT "SAVING ..WAIT"
910 PRINT CHR$ (4);"OPEN";NAME$ + "," + DR$
930 PRINT CHR$ (4);"WRITE";NAME$
940 PRINT HOLE: PRINT DIV
950 FOR I = 1 TO DIV: PRINT X%(I): PRINT Y%(I): NEXT I
960 PRINT CHR$ (4);"CLOSE"
970 GOTO 760
980 HOME : PRINT TAB( 16);" STATS DATA "
990 PRINT TAB( 10);"AMPLITUDE"; TAB( 25);"OCCURANCE": FOR I = 1 TO 38: PRINT
    "-";: NEXT I: PRINT "  "
```

```
1000  FOR I = 1 TO DIV
1010  PRINT  TAB( 14);X%(I); TAB( 28);Y%(I)
1020  NEXT I
1022  GET Z$: HOME : GOTO 760
1030  HOME : VTAB 3: INPUT "ANOTHER SET OF READING (Y/N) ?";AN$
1040  IF AN$ = "N" THEN 1120
1050  IF AN$ < > "Y" THEN 1030
1060  FOR I = 1 TO DIV:Y%(I) = 0: NEXT I
1070  PRINT : PRINT "SATISFY WITH ";PTS;" POINTS & ";D;" DELAY"
1080  VTAB 7: INPUT "(Y/N) ?";AN$
1090  IF AN$ = "Y" THEN 250
1100  IF AN$ = "N" THEN 180
1110  GOTO 1080
1120  END
```

```
10  REM   ********************************
20  REM   * STATISTICAL ANALYSIS PROGRAM *
30  REM   * OPTIONS AVAILABLE :-         *
40  REM   *  1. DATA PERPARATION         *
50  REM   *  2. GROUPING RAW DATA        *
60  REM   *  3. READ/PRINT RAW DATA      *
70  REM   *  4. PRINT STATISTICAL DATA   *
80  REM   *  5. PRINT STATISTICAL RESULTS*
90  REM   *  6. STATISTICAL ANALYSIS     *
100  REM  *   NOTE:-PRINTING DONE ON     *
110  REM  *        SCREEN OR PRINTER     *
120  REM  ********************************
130  DATA  "HOLE#","MEAN","STD","SKEW","KURT","RMS"
140  DIM X(150),Y(150),HED$(9),DDM(150,10),YY(500)
150  DIM A%(5000)
160  FOR I = 1 TO 6: READ HED$(I): NEXT I
170  REM
180  REM
190  HOME : HTAB 34: PRINT "P2 V1.0"
200  POKE 34,0: VTAB 3: PRINT  TAB( 4)":::: STATISTICAL SIGNAL ANALYSIS :
     ::::": PRINT  TAB( 4): FOR I = 1 TO 37: PRINT "=";: NEXT I: PRINT
210  PRINT  TAB( 10);"1). DATA PREPARATION ?"
220  PRINT  TAB( 10);"2). GROUP RAW DATA ?"
230  PRINT  TAB( 10);"3). READ/PRINT RAW DATA ?"
240  PRINT  TAB( 10);"4). PRINT STATS. DATA ?"
250  PRINT  TAB( 10);"5). PRINT STATS RESULTS ?"
260  PRINT  TAB( 10);"6). STATS. ANALYSIS ?"
270  PRINT  TAB( 10);"7). EXIT ?": POKE 34,11
280  PRINT : HTAB 6: INPUT "PRESS NUMBER TO RESPONSE (1-7):";RES$
290  REM
300  REM
310  IF RES$ < "1" OR RES$ > "7" THEN  VTAB 14: GOTO 280
320  POKE 34,0
330  REM
340  IF RES$ = "2" THEN  HOME : VTAB 2: PRINT  TAB( 5);"::: GROUPING RAW
     DATA :::": POKE 34,3: GOSUB 2410: POKE 34,0
350  REM
360  IF RES$ = "7" THEN 480
370  REM
380  IF RES$ = "1" THEN  HOME : VTAB 2: PRINT  TAB( 8);"::: DATA PREPARAT
     ION :::": POKE 34,3: GOSUB 2750: POKE 34,0
390  REM
400  IF RES$ = "3" THEN  HOME : VTAB 2: PRINT  TAB( 8);"::: READ/PRINT RA
     W DATA :::": POKE 34,3: GOSUB 500: POKE 34,0
410  REM
420  IF RES$ = "4" THEN  HOME : VTAB 2: PRINT  TAB( 6);":::  PRINT STATIS
     TICAL DATA  :::": POKE 34,3: GOSUB 1860: POKE 34,0
430  REM
440  IF RES$ = "6" THEN  HOME : VTAB 2: PRINT  TAB( 6);":::  STATISTICAL
     ANALISIS  :::": POKE 34,3: GOSUB 900: POKE 34,0
450  REM
460  IF RES$ = "5" THEN  HOME : VTAB 2: HTAB 6: PRINT "::: PRINT STATISTI
     CAL RESULTS :::": POKE 34,3: GOSUB 2290: PRINT : HTAB 10: INPUT "# S
     ET OF READINGS :";IC: GOSUB 1500: POKE 34,0
470  GOTO 190
```

```
480  END
490  REM
500  REM  ****************************
510  REM   *   READ/PRINT RAW DATA    *
520  REM  ****************************
530  GOSUB 2290
540  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
550  HOME : VTAB 5: PRINT  TAB( 5);"WAIT....READING DATA FROM..";NAME$
560  PRINT  CHR$ (4);"READ";NAME$
570  INPUT HOLE: INPUT PTS
580  FOR I = 1 TO PTS
590  INPUT A%(I): NEXT I
600  PRINT  CHR$ (4);"CLOSE"
610  HOME : VTAB 5: HTAB 8: PRINT "==>";NAME$" HAS ";PTS;" POINTS <=="
620  VTAB 7: HTAB 10: PRINT "1). PRINT ALL POINTS ?": PRINT  TAB( 10);"2)
     . SOME INTERVAL ?": PRINT  TAB( 10);"3). CONTINUE ?"
630  VTAB 12: HTAB 10: INPUT "SELECTION (1/2/3) :";AN
640  IF AN < 1 OR AN > 3 THEN 630
650  IF AN = 3 THEN 720
660  IF AN = 1 THEN FF = 1:LL = PTS: GOTO 690
670  PRINT : HTAB 10: INPUT "STARTING POINTS :";FF
680  HTAB 10: INPUT "ENDING POINT :";LL
690  GOSUB 1790
700  GOSUB 750
710  GET Z$: HOME : GOTO 610
720  RETURN
730  REM  ****************************
740  REM  *  PRINT RAW DATA-PRINTER  *
750  REM  ****************************
760  IF AN = 2 THEN 840
770  PR# 1: PRINT  CHR$ (9);"80N": POKE 36,20: PRINT "POINT #";: POKE 36,
     40: PRINT "AMPLITUDE"
780  FOR I = FF TO LL
790  PRINT I;: PRINT "  ";: PRINT  LEFT$ ( STR$ (A%(I)),5);: PRINT "  ";
800  NEXT I
810  PR# 0: GOTO 890
820  REM  ****************************
830  REM  *  PRINT RAW DATA-SCREEN   *
840  REM  ****************************
850  HOME : VTAB 4: PRINT  TAB( 10);"POINT #"; TAB( 25);"AMPLITUDE": FOR
     I = 1 TO 38: PRINT "-";: NEXT I: PRINT "  ": POKE 34,5
860  FOR I = FF TO LL
870  PRINT  TAB( 13);I; TAB( 27);A%(I)
880  NEXT I
890  POKE 34,3: RETURN
900  REM  *****************************
910  REM  *   STATISTICAL ANALYSIS    *
920  REM  *****************************
930  HOME : VTAB 3: PRINT  TAB( 13);"FOR 'SD' :-": GOSUB 2290
940  HTAB 13: PRINT "DATA SELECTION :-"
950  PRINT  TAB( 13);"1). UNGROUPED DATA ?": PRINT  TAB( 13);"2). GROUPED
      DATA ?": PRINT  TAB( 13);"3). PROB. DENSITY ?"
960  HTAB 13: INPUT "SELECTION (1-3) :";AN
970 NBM$ = NAME$:DD$ = DR$
980  HTAB 5: INPUT "WANT TO STORE STATS RESULTS (Y/N) ?";AA$
```

```
990  IF AA$ = "Y" THEN  HOME : VTAB 3: CALL  - 868: PRINT  TAB( 13);"FOR
     'SR' :-": GOSUB 2290: GOTO 1010
1000  IF AA$ <  > "N" THEN 980
1010  HOME
1020  PRINT  CHR$ (4);"OPEN";NBM$ + "," + DD$
1030  PRINT  CHR$ (4);"READ";NBM$
1040  FOR I = 0 TO 5:SUM(I) = 0: NEXT I
1050  INPUT HOLE: INPUT PTS
1060  FOR I = 1 TO PTS
1070  INPUT X(I): INPUT Y(I)
1080  NEXT I
1090  PRINT  CHR$ (4);"CLOSE"
1100  VTAB 10: PRINT  TAB( 10);NAME$;"   ";NBM$
1110  VTAB 23: CALL  - 868: HTAB 5: PRINT "* WAIT! PROCESSING...."
1120  FOR I = 1 TO PTS
1130 SUM(0) = SUM(0) + Y(I) ^ 2
1140  ON AN GOTO 1150,1160,1170
1150 SUM(1) = SUM(1) + Y(I): GOTO 1180
1160 SUM(1) = SUM(1) + Y(I):SUM(2) = SUM(2) + X(I) * Y(I): GOTO 1180
1170 SUM(1) = SUM(1) + X(I) * Y(I)
1180  NEXT I
1190 RSM = (SUM(0) / PTS) ^ 0.5
1200  ON AN GOTO 1210,1220,1230
1210 YMEAN = SUM(1) / PTS:SUM(1) = 0: GOTO 1240
1220 YMEAN = SUM(2) / SUM(1):SUM(2) = 0: GOTO 1240
1230 YMEAN = SUM(1):SUM(1) = 0
1240 DY = MX
1250  FOR I = 1 TO PTS
1260  IF AN = 1 THEN YDEV = Y(I) - DY: GOTO 1280
1270 YDEV = X(I) - DY
1280  FOR J = 2 TO 4
1290  IF AN = 1 THEN SUM(J) = SUM(J) + YDEV ^ J: GOTO 1310
1300 SUM(J) = SUM(J) + YDEV ^ J * Y(I)
1310  NEXT J
1320  NEXT I
1330  IF AN = 3 THEN 1380
1340  FOR I = 2 TO 5
1350  IF AN = 1 THEN SUM(I) = SUM(I) / PTS: GOTO 1370
1360 SUM(I) = SUM(I) / SUM(1)
1370  NEXT I
1380 YSTD = SUM(2) ^ 0.5
1390 SK = SUM(3) / YSTD ^ 3
1400 KUR = SUM(4) / YSTD ^ 4
1410  PRINT "HOLE#= ";HOLE;"  MEAN= ";YMEAN;"  STA.D= ";YSTD
1420  PRINT "SKEW= ";SK;"  KURT.=";KUR;"  RMS =";RSM
1430  IF AA$ = "N" THEN 1490
1440  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
1450  PRINT  CHR$ (4);"APPEND";NAME$
1460  PRINT  CHR$ (4);"WRITE";NAME$
1470  PRINT HOLE: PRINT YMEAN: PRINT YSTD: PRINT SK: PRINT KUR: PRINT RSM

1480  PRINT  CHR$ (4);"CLOSE";NAME$
1490  RETURN
1500  REM  ******************************
1510  REM  * PRINT STATISTICAL RESULTS *
1520  REM  ******************************
```

```
1530  HOME : VTAB 10: HTAB 8: PRINT "WAIT! READING RESULTS....."
1540  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
1550  PRINT  CHR$ (4);"READ";NAME$
1560  FOR I = 1 TO IC: FOR J = 1 TO 6: INPUT DDM(I,J): NEXT J: NEXT I
1570  PRINT  CHR$ (4);"CLOSE"
1580  IF AN = 3 THEN 1780
1590  IF AN = 2 THEN 1700
1600  REM  ******************************
1610  REM  *  PRINT (SR) - PRINTER      *
1620  REM  ******************************
1630  PR# 1: PRINT  CHR$ (9);"80N"
1640  POKE 36,3:J = 1: FOR I = 4 TO 57 STEP 9: POKE 36,I: PRINT HED$(J);:
     J = J + 1: NEXT I: PRINT " "
1650  FOR I = 1 TO IC
1660  POKE 36,3:J = 1: FOR K = 4 TO 57 STEP 9: POKE 36,K: PRINT  LEFT$ ( STR$
     (DDM(I,J)),5);:J = J + 1: NEXT K: PRINT ""
1670  NEXT I
1680  PR# 0
1690  GOTO 1750
1700  REM  ******************************
1710  REM  *  PRINT (SR) - SCREEN       *
1720  REM  ******************************
1730  HOME : VTAB 2:J = 1: FOR I = 3 TO 33 STEP 6: PRINT  TAB( I);HED$(J)
     ;:J = J + 1: NEXT I: PRINT "  ": FOR I = 1 TO 38: PRINT "-";: NEXT I
     : PRINT "  "
1740  FOR I = 1 TO IC
1750  FOR J = 1 TO 6: PRINT  TAB( J - 1 * 6); LEFT$ ( STR$ (DDM(I,J)),5);
     : NEXT J
1760  NEXT I
1770  GET Z$
1780  RETURN
1790  REM   ******************************
1800  REM   * OUTPUT DEVICE SELECTION    *
1810  REM   ******************************
1820  HOME : VTAB 5: HTAB 13: PRINT "1). PRINTER ?": PRINT  TAB( 13);"2).
      SCREEN ?": PRINT  TAB( 13);"3). CONTINUE ?"
1830  VTAB 9: HTAB 13: INPUT "SELECTION (1/2/3) :";AN
1840  IF AN < 1 OR AN > 3 THEN 1830
1850  RETURN
1860  REM  ******************************
1870  REM  *   PRINT STATISTICAL DATA   *
1880  REM  ******************************
1890  GOSUB 2290
1900  GOSUB 1790
1910  HOME
1920  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
1930  PRINT  CHR$ (4);"READ";NAME$
1940  INPUT HOLE: INPUT PTS
1950  FOR I = 1 TO PTS: INPUT X(I): INPUT Y(I): NEXT I
1960  PRINT  CHR$ (4);"CLOSE"
1970  IF AN = 1 THEN 2070
1980  IF AN = 3 THEN 2160
```

```
1990  REM  ****************************
2000  REM  *   PRINT (SD) - SCREEN     *
2010  REM  ****************************
2020  PRINT  CHR$ (4);"CLOSE"
2030  VTAB 4: CALL  - 868: PRINT  TAB( 6);"POINT #"; TAB( 16);"AMPLITUDE"
     ; TAB( 29);"# OCCR": POKE 34,4
2040  FOR K = 1 TO PTS
2050  CALL  - 868: PRINT  TAB( 8);K; TAB( 19);X(K); TAB( 30);Y(K): NEXT K

2060  GET Z$: POKE 34,3: GOTO 2160
2070  REM  ****************************
2080  REM  *   PRINT (SD) - PRINTER    *
2090  REM  ****************************
2092  INPUT "COL# :";U
2100  PR# 1: PRINT  CHR$ (9);"80N"
2120  FOR I = 1 TO PTS
2130  POKE 36,U: PRINT  LEFT$ ( STR$ (X(I)),5);: POKE 36,U + 6: PRINT  LEFT$
     ( STR$ (Y(I)),5)
2140  NEXT I
2150  PR# 0
2160  RETURN
2170  REM  ****************************
2180  REM  *   SEE CATALOG (D1/D2)    *
2190  REM  ****************************
2200  HOME
2210  VTAB 5: HTAB 9: PRINT "? WANT TO SEE CATALOG IN :-": PRINT
2220  PRINT  TAB( 10);"1). DRIVE 1 ?": PRINT  TAB( 10);"2). DRIVE 2 ?": PRINT
      TAB( 10);"3). CONTINUE ?".
2230  VTAB 12: HTAB 10: INPUT "SELECTION (1/2/3) :";SEL
2240  IF SEL = 1 THEN  PRINT  CHR$ (4);"CATALOG,D1"
2250  IF SEL = 2 THEN  PRINT  CHR$ (4);"CATALOG,D2"
2260  IF SEL = 3 THEN 2280
2270  GET Z$: GOTO 2200
2280  GET Z$: HOME : RETURN
2290  REM  ****************************
2300  REM  *    FILE MANAGEMENT       *
2310  REM  ****************************
2320  VTAB 5
2330  HTAB 13: INPUT "FILENAME :";NAME$
2340  HTAB 13: INPUT "STORE DRIVE(D1/D2) :";DR$
2350  VTAB 9: HTAB 8: INPUT "SATISFY ? Y/N,(C)AT,(R)ESTART :";AN$
2360  IF AN$ = "C" THEN  GOSUB 2170: GOTO 2320
2370  IF AN$ = "N" THEN 2320
2380  IF AN$ = "R" THEN  POKE 34,0: HOME : GOTO 200
2390  IF AN$ <  > "Y" THEN 2350
2400  RETURN
2410  REM  ****************************
2420  REM  *       GROUPING (RD)      *
2430  REM  ****************************
2440  VTAB 5: HTAB 3: INPUT "DATA AVAILABLE IN MEMORY (Y/N) ? ";AN$
2450  IF AN$ = "N" THEN  GOSUB 500: GOTO 2480
2460  IF AN$ <  > "Y" THEN 2440
2480  HTAB 8: INPUT " NUMBER OF DIVISION :";DIV
2490 INC = 4096 / DIV
```

```
2492 X(0) = 0
2500  FOR K = 1 TO DIV
2510 X(K) = K * INC:Y(K) = 0: NEXT K
2520  FOR J = 1 TO PTS
2530 RRNT =  INT (A%(J) / INC)
2540 Y(RRNT + 1) = Y(RRNT + 1) + 1
2550  NEXT J
2560  HOME : VTAB 10: PRINT  TAB( 10);"WAIT......SAVING";TX
2592 DL = X(CF - 1)
2600  FOR I = CF TO CL
2602 DU = X(I)
2610 X(I) = (DL + DU) / 2:DL = DU
2620  NEXT I
2630  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
2640  PRINT  CHR$ (4);"APPEND";NAME$
2650  PRINT  CHR$ (4);"WRITE";NAME$
2660  PRINT HOLE: PRINT DIV
2670  FOR I = 1 TO DIV
2680  PRINT X(I): PRINT Y(I)
2690  NEXT I
2700  PRINT  CHR$ (4);"CLOSE"
2710  FOR I = 1 TO DIV:Y(I) = 0: NEXT I
2720  NEXT TX
2730  HOME : VTAB 10: PRINT  TAB( 10);"GROUPING..";NAME$;"...DONE"
2740  GET Z$: RETURN
2750  REM  ****************************
2760  REM  *     DATA PERPARATION     *
2770  REM  *  EXPRESS :-              *
2780  REM  *  AMPLITUDE IN 'EU'-X(I)  *
2790  REM  *  FREQUENCY IN '%' -Y(I)  *
2800  REM  ****************************
2810  HOME
2820  VTAB 3: HTAB 8: INPUT "SD IN MEMORY (Y/N, Q) ?";AN$
2830  IF AN$ = "Y" THEN 2860
2840  PRINT  TAB( 8);"..GO AND GET (SD)...": GET Z$
2850  GOTO 3130
2860  VTAB 4: HTAB 8: INPUT "AMPL. CAL. SIGNAL :";CS
2870  HTAB 8: INPUT "MEAN (CAL. SIGNAL) :";ME
2880 SS = 0
2890  FOR I = 1 TO PTS
2900 SS = SS + Y(I)
2910 DD = (X(I) - MX) / CS
2920 X(I) = DD
2930  NEXT I
2940  FOR I = 1 TO PTS
2950  IF SS = 0 THEN Y(I) = Y(I): GOTO 2970
2960 Y(I) = Y(I) / SS * 100
2970  NEXT I
2980  HTAB 8: INPUT "DISPLAY 'SD' (Y/N) ?";AN$
2990  IF AN$ = "N" THEN 3010
3000  FOR I = 1 TO PTS: PRINT X(I),Y(I): NEXT I
3010  PRINT : HTAB 8: INPUT "STORE DATA (Y/N) ?";AN$
```

```
3020  IF AN$ = "N" THEN 3130
3030  IF AN$ < > "Y" THEN 3010
3040  GOSUB 2290
3050  PRINT : HTAB 8: PRINT "STORING DATA....."
3060  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
3070  PRINT  CHR$ (4);"WRITE";NAME$
3080  PRINT HOLE: PRINT PTS
3090  FOR I = 1 TO PTS
3100  PRINT X(I): PRINT Y(I)
3110  NEXT I
3120  PRINT  CHR$ (4);"CLOSE"
3130  RETURN

]
```

C.3. PLOTTING AND CURVE-FITTING PROGRAM.

```
10  CALL  PEEK (175) + 256 *  PEEK (176) - 46
20  & "RELOCATE"
40 LB$ = "X-AXIS"
50 LL$ = "Y-AXIS"
60 LT$ = "X VS Y"
80  DIM A(10,10),R(10),V(10),P(20)
90  DIM X(200),Y(200),B(10)
130 OC$ = "N"
140  HOME : VTAB 2: HTAB 10: INVERSE : PRINT "PLOTTING & CURVE-FIT": NORMAL
     : POKE 34,2
150  VTAB 5: HTAB 5: INPUT "DATA AVAILABLE ON FILE (Y/N) ?";AN$
160  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN  VTAB 5: CALL  - 958: GOTO 150

170  IF AN$ = "Y" THEN 272
180  GOSUB 1150
220  GOSUB 1000
272 Y7 = 1E38:Y8 =  - 1E38:X7 = 1E38:X8 =  - 1E38
280  HOME : VTAB 4: HTAB 10: PRINT "1. DATA ?": PRINT  TAB( 10);"2. RESUL
     TS ?": PRINT  TAB( 10);"3. RESTART ?": PRINT  TAB( 10);"4. QUIT ?"
285  VTAB 8: HTAB 10: INPUT "SECTION (1-4) :";SEL$
290  IF  VAL (SEL$) < 1 OR  VAL (SEL$) > 4 THEN 285
295  IF SEL$ = "3" THEN 130
300  IF SEL$ = "4" THEN 890
305  IF SEL$ = "1" THEN NC = 2:XX = 1:YY = 2: GOTO 500
310  PRINT : HTAB 10: INPUT "NUMBER OF ROW :";NP
315  HTAB 10: INPUT "NUMBER OF COLUMN :";NC
320  HTAB 10: INPUT "X-AXIS (XX) :";XX
325  HTAB 10: INPUT "Y-AXIS (YY) :";YY
500  GOSUB 7000
510  HOME : VTAB 14: HTAB 11: FLASH : PRINT "WAIT...READING ";NAME$: NORMAL

802  PRINT  CHR$ (4);"OPEN";NAME$ + "," + DR$
804  PRINT  CHR$ (4);"READ";NAME$
806  IF SEL$ = "1" THEN  INPUT HOLE: INPUT NP
808  FOR I = 1 TO NP
810  FOR J = 1 TO NC: INPUT DMY(J): NEXT J
811 X(I) = DMY(XX):Y(I) = DMY(YY)
812  GOSUB 940
816  NEXT I
820  PRINT  CHR$ (4);"CLOSE"
830  GOSUB 1000
850  GOTO 140
890  HOME : VTAB 12: HTAB 12: FLASH : PRINT "HAVE A NICE DAY": NORMAL
895  END
940  REM : DETERMINE MAX X&Y AND MIN X&Y
950  IF Y(I) > Y8 THEN Y8 = Y(I)
960  IF Y(I) < Y7 THEN Y7 = Y(I)
970  IF X(I) > X8 THEN X8 = X(I)
980  IF X(I) < X7 THEN X7 = X(I)
990  RETURN
1000  REM :DECIDE TO PLOT,CURVE-FIT,PRINT,RESTART OR QUIT
1005  HOME : VTAB 2: CALL  - 868: HTAB 10: PRINT "::: MAIN MENU :::": PRINT
      TAB( 10);"================="
```

```
1010  VTAB 5: HTAB 10: PRINT " 1). PLOTTING ?"
1020  HTAB 10: PRINT " 2). CURVE-FIT ?"
1030  HTAB 10: PRINT " 3). DATA MANIPULATION ?"
1035  HTAB 10: PRINT " 4). VIEW PLOT ?"
1037  HTAB 10: PRINT " 5). CONTINUE (GRAPH OVERLAY)?"
1040  HTAB 10: PRINT " 6). RESTART ?"
1050  HTAB 10: PRINT " 7). QUIT ? ": POKE 34,14: POKE 35,15
1060  VTAB 15: HTAB 5: INPUT "TYPE NUMBER TO RESPONSE (1-7) :";ZZ$
1070  IF  VAL (ZZ$) < 1 OR  VAL (ZZ$) > 7 THEN 1060
1075  POKE 34,1: POKE 35,24
1080  ON  VAL (ZZ$) GOSUB 2410,3330,5000,4000
1110  IF  VAL (ZZ$) = 5 THEN 140
1120  IF  VAL (ZZ$) = 6 THEN 130
1121  IF  VAL (ZZ$) = 7 THEN 890
1130  GOTO 1000
1140  RETURN
1150  REM : ENTER SOME DATAS TO PLAY WITH
1160  HOME : VTAB 5: HTAB 7: INPUT "WANT TO INPUT DATA (Y/N) ?";AN$
1170  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN  GOTO 1160
1180  IF AN$ = "Y" THEN 1230
1190  PRINT : HTAB 10: INPUT "(Q)UIT,(R)ESTART ?";AN$
1200  IF  NOT (AN$ = "Q" OR AN$ = "R") THEN  GOTO 1190
1210  IF AN$ = "R" THEN 130
1220  IF AN$ = "Q" THEN 890
1230 MX = 100
1240 Y7 = 1E38:Y8 =  - 1E38:X7 = 1E38:X8 = - 1E38
1260 Q = MD * 2:EF = 999:J = 0
1270  HOME : VTAB 1: PRINT  TAB( 8);"DATA PAIRS ALLOWED :";MX: PRINT  TAB(
     8)"TO END INPUT: TYPE 999,999": POKE 34,3: VTAB 4
1280 J = J + 1: HTAB 8: PRINT "X(";J;"),Y(";J;") =";: INPUT X(J),Y(J)
1290  IF X(J) = EF AND Y(J) = EF THEN J = J - 1: POKE 34,0: GOTO 1330
1300  IF J = MX THEN  PRINT : PRINT  TAB( 10);"NO MORE DATA ALLOWED": GOTO
     1330
1310 I = J: GOSUB 940: GOTO 1280
1330 NP = J
1340  IF NP = 0 THEN  GOSUB 1800: PRINT  TAB( 10);"NO DATA ENTERED": GOTO
     1160
1380  RETURN
1390  REM :      POLYNOMIAL   CURVE-FIT BY LEAST SQUARE
1400  HOME
1410  PRINT NP;" DATA PAIRS ENTERED": PRINT
1420 MD = 7: REM  7D ONLY
1430  PRINT : INPUT "DEGREE OF POLYNOMIAL TO BE FITTED? ";D: PRINT
1440  IF D < 0 THEN  GOSUB 1780: PRINT "DEGREE MUST BE >= 0": GOTO 1430
1450 D =  INT (D): IF D < NP THEN 1470
1460  GOSUB 1780: PRINT "NOT ENOUGH DATA": GOTO 1430
1470 D2 = 2 * D: IF D > MD THEN  GOSUB 1780: PRINT "DEGREE TOO HIGH": GOTO
     1430
1480 N = D + 1
1490  FOR J = 1 TO D2:P(J) = 0: FOR K = 1 TO NP
1500 P(J) = P(J) + X(K) ^ J: NEXT : NEXT :P(0) = NP
1510 R(1) = 0: FOR J = 1 TO NP:R(1) = R(1) + Y(J)
1520  NEXT : IF N = 1 THEN 1550
1530  FOR J = 2 TO N:R(J) = 0: FOR K = 1 TO NP
```

```
1540 R(J) = R(J) + Y(K) * X(K) ^ (J - 1): NEXT : NEXT
1550  FOR J = 1 TO N: FOR K = 1 TO N:A(J,K) = P(J + K - 2): NEXT : NEXT
1560  GOSUB 1820
1570  PRINT : PRINT  TAB( 1);"X POWER          COEFFICIENT"
1580  PRINT  TAB( 1);: FOR J = 1 TO 7: PRINT "-";: NEXT : PRINT  TAB( 17)
 ;
1590  FOR J = 1 TO 11: PRINT "-";: NEXT : PRINT
1600  FOR J = 1 TO N: PRINT "    ";J - 1,V(J): NEXT : PRINT : PRINT
1610 Q = 0: FOR J = 1 TO NP:Q = Q + Y(J): NEXT :M = Q / NP:T = 0:G = 0: FOR
     J = 1 TO NP
1620 Q = 0: FOR K = 1 TO N:Q = Q + V(K) * X(J) ^ (K - 1): NEXT :T = T + (
     Y(J) - Q) ^ 2
1630 G = G + (Y(J) - M) ^ 2: NEXT : IF G = 0 THEN T = 100: GOTO 1650
1640 T = 100 *  SQR (1 - T / G)
1650  PRINT "PERCENT GOODNESS OF FIT= ";T
1660  PRINT : PRINT "-- CONTINUATION OPTIONS --": PRINT
1670  PRINT "  1 - DETERMINE SPECIFIC POINTS"
1680  PRINT "  2 - FIT ANOTHER DEGREE TO SAME DATA"
1690  PRINT "  3 - END CURVE-FIT": PRINT
1700  INPUT "WHAT NEXT? ";Q:Q =  INT (Q): IF Q = 3 THEN 2000
1710  IF Q = 2 THEN 1430
1720  IF Q <  > 1 THEN 1660
1730  PRINT : PRINT : PRINT "ENTER ";EF;" TO LEAVE THIS MODE"
1740  PRINT : INPUT "X=? ";XV: IF XV = EF THEN 1660
1750 YV = 0: FOR K = 1 TO N
1760 YV = YV + V(K) * XV ^ (K - 1): NEXT : PRINT "Y= ";YV
1770  GOTO 1740
1780  PRINT "** ";: FLASH : PRINT "ERROR!";: NORMAL
1790  PRINT " ** -- ";: RETURN
1800  PRINT "** ";: FLASH : PRINT "FATAL ERROR!";: NORMAL
1810  PRINT " ** -- ";: RETURN
1820  IF N = 1 THEN V(1) = R(1) / A(1,1): RETURN
1830  FOR K = 1 TO N - 1
1840 I = K + 1
1850 L = K
1860  IF  ABS (A(I,K)) >  ABS (A(L,K)) THEN L = I
1870  IF I < N THEN I = I + 1: GOTO 1860
1880  IF L = K THEN 1920
1890  FOR J = K TO N:Q = A(K,J):A(K,J) = A(L,J)
1900 A(L,J) = Q: NEXT
1910 Q = R(K):R(K) = R(L):R(L) = Q
1920 I = K + 1
1930 Q = A(I,K) / A(K,K):A(I,K) = 0
1940  FOR J = K + 1 TO N:A(I,J) = A(I,J) - Q * A(K,J): NEXT
1950 R(I) = R(I) - Q * R(K): IF I < N THEN I = I + 1: GOTO 1930
1960  NEXT
1970 V(N) = R(N) / A(N,N): FOR I = N - 1 TO 1 STEP  - 1
1980 Q = 0: FOR J = I + 1 TO N:Q = Q + A(I,J) * V(J)
1990 V(I) = (R(I) - Q) / A(I,I): NEXT : NEXT
2000  RETURN
2410  REM  : LET'S  DO SOME PLOTTING
2415  IF OC$ = "Y" THEN  & "CHART",GMD: GOTO 2762
2420  HOME : PRINT " VALUES DETERMINE FROM DATA ": PRINT " --------------
     ------------- "
2430  PRINT " Xmin,Xmax =";: PRINT  TAB( 15);X7;: PRINT  TAB( 30);X8
```

```
2440  PRINT " Ymin,Ymax =";: PRINT  TAB( 15);Y7;: PRINT  TAB( 30);Y8
2450  VTAB 8: PRINT : INPUT " XMIN,XMAX ? ";XF,XL
2460  INPUT " YMIN,YMAX ? ";MIY,MAY
2470  INPUT " XSEP,YSEP ? ";XS,YS
2472  INPUT "SATISFY (Y/N) ?";AN$
2474  IF AN$ = "N" THEN 2450
2480  HOME : VTAB 2: PRINT " LABEL FOR :": HTAB 2: PRINT "1). X-AXIS:",LB
     $: PRINT  TAB( 2);"2). Y- AXIS:",LL$: HTAB 2: PRINT "3). TITLE:",LT$

2490  INPUT " SATISFY WITH THE LABELLING ? (Y/N) ";AN$
2500  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN 2480
2510  IF AN$ = "Y" THEN 2530
2520  INPUT " X-AXIS LABEL ";LB$: INPUT " Y-AXIS LABEL ";LL$: INPUT " TIT
     LE OF GRAPH ";LT$
2530  & "CHART",GGO(1)
2550  & "CHART",CLP(40,265,40,180): & "CHART",FRM
2560  & "CHART",SCL(XF,XL,MIY,MAY)
2570  GOSUB 3030
2580  FOR I = XF TO XL STEP XS
2590 II = I + XS
2600  & "CHART",HLB( STR$ (II),II,U2, - 5)
2610  NEXT I
2620  FOR I = MIY TO MAY STEP YS
2630  & "CHART",HLB( STR$ (I),U1,I, - 8)
2640  NEXT I
2690  GOTO 2700
2700 MN = (40 + 265) / 2 - ( LEN (LB$) / 2) * 6.2
2710  & "CHART",STU(MN,22,U1,U2)
2720  & "CHART",HLB(LB$,U1,U2, - 2)
2730 MN = (180 + 40) / 2 - ( LEN (LL$) / 2) * 7
2740  & "CHART",STU(6,MN,U1,U2)
2750  & "CHART",VLB(LL$,U1,U2, - 6)
2752 MN = (40 + 265) / 2 - ( LEN (LT$) / 2) * 6.2
2754  & "CHART",STU(MN,187,U1,U2)
2755  & "CHART",HLB(LT$,U1,U2, - 2)
2762  FOR I = 1 TO NP
2764  & "CHART",HLB("+",X(I),Y(I),5)
2766  NEXT I
2780  & "CHART",MIX: HOME
2790  VTAB 23: INPUT " WANT TO CURVE-FIT THE DATAS ? ";CN$
2800  IF  NOT (CN$ = "Y" OR CN$ = "N") THEN 2790
2810  IF CN$ = "N" THEN 2890
2820  & "CHART",TMD: GOSUB 3330
2830  & "CHART",GMD: & "CHART",NMX
2840  GOSUB 3150
2850  & "CHART",MIX
2860  HOME : VTAB 23: HTAB 2: INPUT "WANT TO OVERLAY CORR. CURVE (Y/N) ?"
     ;AN$
2870  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN 2860
2880  IF AN$ = "Y" THEN 2820
2890  HOME : VTAB 23: INPUT " WANT TO SAVE THE PLOT (Y OR N) ?";AN$
2900  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN 2890
2910  IF AN$ = "N" THEN 2960
2920  HOME : VTAB 22: INPUT "FILENAME TO STORE THE PLOT ";NAME$
2930  INPUT "WHERE TO STORE ( D1 OR D2 ) ?";DR$
```

```
2940  IF  NOT (DR$ = "D1" OR DR$ = "D2") THEN 2930
2950  PRINT  CHR$ (4);"BSAVE";NAME$ + "," + DR$ + ",A$2000,L$2000"
2960  HOME : VTAB 23: INPUT " WANT TO GET A DUMP OF THE PLOT ?";AN$
2970  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN 2960
2980  IF AN$ = "N" THEN 3012
2990  HOME : VTAB 22: HTAB 5: FLASH : PRINT "MAKE SURE THAT THE PRINTER I
     S ON": NORMAL : VTAB 23: HTAB 12: PRINT "PRESS 'Q' TO EXIT": GET Z$:
      IF Z$ = "Q" THEN 3012
3000  PR# 1: PRINT  CHR$ (9);"G": PR# 0
3012  HOME : VTAB 23: HTAB 5: INPUT "WANT TO OVERLAY PLOTS (Y/N)?";OC$
3013  IF  NOT (OC$ = "Y" OR OC$ = "N") THEN 3012
3015  GET ZZ$: & "CHART",TMD
3029  RETURN
3030  REM :WHERE TO PUT THE CROSSING OF AXES
3040 XO = 0:YO = 0
3050  IF XL < 0 AND XF < 0 THEN XO = XL
3060  IF MAY < 0 AND MIY < 0 THEN YO = MAY
3070  IF XL > 0 AND XF > 0 THEN XO = XF
3080  IF MAY > 0 AND MIY > 0 THEN YO = MIY
3090  HCOLOR= 3
3100  & "CHART",AXS(XS,YS,XO,YO)
3110  & "CHART",STU(38,32,U1,U2): & "CHART",STU(32,32,U3,U4)
3120  IF XO = 0 THEN 3140
3130  & "CHART",HLB( STR$ (XO),U3,U2, - 5)
3140  RETURN
3150  REM : PLOT THE CORRELATION CURVE
3160  & "CHART",SCL(XF,XL,MIY,MAY)
3170 SEP =  ABS ((XL - XF) / 100)
3180 I = XF
3190  IF IC = 2 AND XF = 0 THEN I = I + SEP
3200  IF I > XL THEN 3320
3210  ON IC GOTO 3220,3230,3240,3250,3260
3220 SUM = A + B * I: GOTO 3300
3230 SUM = A + B *  LOG (I): GOTO 3300
3240 SUM = A + I ^ B: GOTO 3300
3250 SUM = A *  EXP (B * I): GOTO 3300
3260 SUM = 0
3270  FOR J = 1 TO N
3280 SUM = SUM + V(J) * I ^ (J - 1)
3290  NEXT J
3300  & "CHART",PLT(I,SUM)
3310 I = I + SEP: GOTO 3190
3320  RETURN
3330  REM :LINEAR,EXPONENTIAL,LOGARITHMIC&POWER CURVE-FIT (LELPCF)
3340  REM :START THE CURVE-FIT PROCESS
3345  HOME : VTAB 2: CALL  - 868: HTAB 2: PRINT ":::::    CURVE-FIT SELECT
     ION    ::::"
3350  VTAB 4: HTAB 5: PRINT "1). LINEAR CURVE-FIT :": HTAB 10: PRINT "Y=a
     +b*X": PRINT
3360  HTAB 5: PRINT "2). LOGARITHMIC CURVE-FIT :": HTAB 10: PRINT "Y=a+b*
     LOG(X)": PRINT
3370  HTAB 5: PRINT "3). POWER CURVE-FIT :": HTAB 10: PRINT "Y=a*X^b": PRINT

3380  HTAB 5: PRINT "4). EXPONENTIAL CURVE-FIT :": HTAB 10: PRINT "Y=a*EX
     P(b*X)": PRINT
3390  HTAB 5: PRINT "5). POLYNOMIAL CURVE-FIT "
```

```
3395  PRINT : HTAB 5: PRINT "6). CONTINUE ?": POKE 34,19: POKE 35,20
3400  VTAB 20: HTAB 5: INPUT "PRESS NUMBER TO RESPONSE (1-6) ";IC
3410  IF IC < 1 OR IC > 6 THEN 3350
3412  POKE 34,0: POKE 35,24
3420  IF IC = 5 THEN  GOSUB 1390: GOTO 3990
3425  IF IC = 6 THEN 3990
3430  REM :COMPUTATION OF REGRESSION AND DETERMINATION COEFFICIENTS
3440 X0 = 0:Y0 = 0:X2 = 0:Y2 = 0:X3 = 0
3450  FOR I = 1 TO NP
3460  ON IC GOTO 3470,3490,3510,3530
3470 C = X(I):D = Y(I)
3480  GOTO 3540
3490 C =  LOG (X(I)):D = Y(I)
3500  GOTO 3540
3510 C =  LOG (X(I)):D =  LOG (Y(I))
3520  GOTO 3540
3530 C = X(I):D =  LOG (Y(I))
3540 X0 = X0 + C:Y0 = Y0 + D
3550 X2 = X2 + C * C:X3 = X3 + C * D:Y2 = Y2 + D * D
3560  NEXT I
3570 X0 = X0 / NP:Y0 = Y0 / NP
3580 B = (X3 - NP * X0 * Y0) / (X2 - NP * X0 * X0)
3590 A = Y0 - B * X0
3600  IF IC < 3 THEN 3620
3610 A =  EXP (A)
3620 R2 = B * B * (X2 - NP * X0 * X0) / (Y2 - NP * Y0 * Y0)
3630  REM :COMPUTE SUM OF SQUARE OF RESIDUALS
3640 S = 0
3650  FOR I = 1 TO NP
3660  ON IC GOTO 3670,3690,3710,3730
3670 S0 = A + B * X(I) - Y(I)
3680  GOTO 3740
3690 S0 = A + B *  LOG (X(I)) - Y(I)
3700  GOTO 3740
3710 S0 = A * (X(I) ^ B) - Y(I)
3720  GOTO 3740
3730 S0 = A *  EXP (B * X(I)) - Y(I)
3740 S = S + S0 * S0
3750  NEXT I
3760  HOME : VTAB 5: HTAB 5: PRINT "REGRESSION COEFFICIENTS:A,B": PRINT  TAB(
      5);"A =";: PRINT  TAB( 9); LEFT$ ( STR$ (A),5);: HTAB 20: PRINT "B =
      ";: PRINT  TAB( 25); LEFT$ ( STR$ (B),5): PRINT
3770  HTAB 5: PRINT "COEFFICIENT OF DETERMINATION:R ": PRINT  TAB( 10); LEFT$
      ( STR$ (R2),5): PRINT
3780  HTAB 5: PRINT "SUM OF SQUARE OF RESIDUALS:S ": PRINT  TAB( 10); LEFT$
      ( STR$ (S),5): PRINT
3790  VTAB 18: HTAB 10: PRINT "1). FIT A POINT ?"
3800  HTAB 10: PRINT "2). ANOTHER CURVE-FIT ?"
3810  HTAB 10: PRINT "3). END CURVE-FIT ?"
3830  VTAB 22: HTAB 8: INPUT "PRESS NUMBER TO RESPONSE (1-3)";ZZ
3840  IF ZZ < 1 OR ZZ > 3 THEN 3830
3850  ON ZZ GOTO 3880,3330,3990
3860  IF AN$ = "2" THEN 3350
3870  IF AN$ = "4" THEN 5020
3880  PRINT : HTAB 10: INPUT "X =";X1
3890  ON IC GOTO 3900,3920,3940,3960
```

```
3900 Y1 = A + B * X1
3910  GOTO 3970
3920 Y1 = A + B *  LOG (X1)
3930  GOTO 3970
3940 Y1 = A * X1 ^ B
3950  GOTO 3970
3960 Y1 = A *  EXP (B * X1)
3970  HTAB 7: PRINT "** X =";X1; TAB( 20);"Y =";Y1
3980  GET Z$: HOME : GOTO 3790
3990  RETURN
4000  REM : VIEW PLOT
4010  & "CHART",GMD
4015  & "CHART",NMX
4020  GET Z$: & "CHART",TMD
4030  RETURN
5000  REM :::DATA MANIPULATION:::
5100  POKE 34,0: HOME : VTAB 3: HTAB 10: PRINT "DATA MANIPULATION": HTAB
    10: FOR I = 1 TO 17: PRINT "-";: NEXT
5160  VTAB 5: HTAB 10: PRINT "1). ADDING DATA ?"
5170  HTAB 10: PRINT "2). CHANGING DATA ?"
5180  HTAB 10: PRINT "3). DELETING DATA ?"
5190  HTAB 10: PRINT "4). VIEW DATA ?"
5200  HTAB 10: PRINT "5). SAVE DATA ?"
5205  HTAB 10: PRINT "6). CONTINUE ?"
5210  VTAB 12: HTAB 5: INPUT "PRESS NUMBER TO RESPONSE (1-6) ";ZZ
5220  IF ZZ < 1 OR ZZ > 6 THEN 5210
5230  IF ZZ = 6 THEN 5330
5250  ON ZZ GOSUB 6000,5340,6090,6210,5580
5252  IF NP = DMY THEN 5325
5285 Y7 = 1E38:Y8 =  - 1E38:X7 = 1E38:X8 =  - 1E38
5290  FOR I = 1 TO NP
5300  GOSUB 940
5320  NEXT I
5325  GOTO 5100
5330  RETURN
5340  REM  :  CHANGE DATA
5350  HOME
5352  VTAB 2: HTAB 10: PRINT "** CHANGE DATA **"
5355  VTAB 5: HTAB 8: INPUT "WHICH POINT ?";II
5357  PRINT
5360  PRINT  TAB( 5);"X(";II;"):";X(II)
5362  PRINT  TAB( 5);"Y(";II;"):";Y(II)
5365  VTAB 10: HTAB 5: INPUT "THIS PAIR ...(Y/N) ?";AN$
5370  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN  VTAB 10: CALL  - 958: GOTO 5
    365
5375  IF AN$ = "N" THEN 5570
5380  VTAB 12: HTAB 5: PRINT "ENTER NEW DATA FOR POINT ";II
5382  PRINT  TAB( 5);"X(";II;"):";: INPUT X(II)
5385  PRINT  TAB( 5);"Y(";II;"):";: INPUT Y(II)
5570  RETURN
5580  REM : SAVING THE DATAS FILE
5582  HOME : VTAB 2: HTAB 10: PRINT "** SAVE DATA **"
5590  VTAB 5: HTAB 10: PRINT "WANT TO SAVE DATA"
5595  VTAB 7: HTAB 10: INPUT "(Y/N) ?";AN$
5600  IF  NOT (AN$ = "Y" OR AN$ = "N") THEN 5595
```

```
5610 IF AN$ = "N" THEN 5710
5615 GOSUB 7000
5620 HOME : VTAB 15: HTAB 13: FLASH : PRINT "WAIT ... SAVING": NORMAL
5640 PRINT CHR$ (4);"OPEN";NAME$ + "," + DR$
5650 PRINT CHR$ (4);"WRITE";NAME$
5660 PRINT HOLE: PRINT NP
5670 FOR I = 1 TO NP
5680 PRINT X(I): PRINT Y(I)
5690 NEXT I
5700 PRINT CHR$ (4);"CLOSE"
5710 RETURN
6000 REM :ADDING
6002 HOME : VTAB 2: HTAB 10: PRINT "** ADDING DATA **": POKE 34,3
6005 VTAB 5: HTAB 10: INPUT "WHICH POINT ?";ST
6020 FOR I = NP TO ST STEP - 1
6030 Y(I + 1) = Y(I):X(I + 1) = X(I)
6040 NEXT I
6050 HOME : VTAB 10: HTAB 7: PRINT "ENTER NEW DATA PAIR FOR :"ST
6060 VTAB 12: HTAB 10: INPUT " X,Y = ?";X(ST),Y(ST)
6070 NP = NP + 1
6080 RETURN
6090 REM :DELETING
6100 HOME : VTAB 2: HTAB 10: PRINT "** DELETE DATA **": POKE 34,3
6110 VTAB 5: HTAB 10: INPUT "WHICH POINT ";ST
6120 IF ST < 1 OR ST > NP THEN HOME : VTAB 5: HTAB 10: PRINT " OUT OF R
     ANGE ": PRINT : HTAB 10: INPUT "TRY AGAIN WHICH POINT ?";ST: GOTO 61
     20
6122 HOME : VTAB 5: HTAB 10: PRINT "DATA PAIR ..";ST
6124 HTAB 10: PRINT "X(";ST;") :";X(ST)
6126 HTAB 10: PRINT "Y(";ST;") :";Y(ST)
6130 VTAB 10: HTAB 5: PRINT "ARE YOU SURE TO DELETE ": HTAB 8: PRINT "DA
     TA PAIR :",ST: VTAB 12: HTAB 10: INPUT "(Y/N) ?";AN$
6140 IF NOT (AN$ = "Y" OR AN$ = "N") THEN 6120
6150 IF AN$ = "N" THEN 6200
6160 FOR I = ST TO NP
6170 X(I) = X(I + 1):Y(I) = Y(I + 1)
6180 NEXT I
6190 NP = NP - 1
6200 RETURN
6210 REM :VIEW DATA
6220 HOME : VTAB 2: HTAB 5: PRINT "POINT #";: HTAB 15: PRINT LB$;: HTAB
     25: PRINT LL$: POKE 34,2
6230 P1 = 15 + LEN (LB$) / 2 + 0.5:P2 = 23 + LEN (LL$) / 2 + 0.5
6240 FOR I = 1 TO NP
6250 CALL - 868: HTAB 7: PRINT I;: HTAB P1: PRINT LEFT$ ( STR$ (X(I)),
     4);: HTAB P2: PRINT LEFT$ ( STR$ (Y(I)),5): NEXT I
6320 GET Z$: POKE 34,0
6330 RETURN
```

```
7000  REM ****** FILE
7010  VTAB 15
7015  HTAB 10: INPUT "FILENAME :";NAME$
7020  HTAB 10: INPUT "STORE DRIVE(D1/D2) :";DR$
7025  VTAB 18: HTAB 5: INPUT "SATISFY (Y/N), (C)AT., (R)ESTART ?";AN$
7030  IF AN$ = "C" THEN  GOSUB 7200: GOTO 7010
7035  IF AN$ = "N" THEN 7010
7040  IF AN$ = "R" THEN 130
7045  IF AN$ <  > "Y" THEN 7025
7050  RETURN
7200  REM :***** CATALOG
7210  HOME
7215  VTAB 5: HTAB 10: PRINT "WANT TO SEE CATALOG IN :"
7220  PRINT  TAB( 10);"1). DRIVE 1 ?": PRINT  TAB( 10);"2). DRIVE 2 ?": PRINT
      TAB( 10);"3). CONTINUE ?"
7225  VTAB 9: HTAB 10: INPUT "SELECTION (1/2/3) :";SEL
7230  IF SEL = 1 THEN  PRINT  CHR$ (4);"CATALOG,D1"
7235  IF SEL = 2 THEN  PRINT  CHR$ (4);"CATALOG,D2"
7240  IF SEL = 3 THEN 7250
7245  GET Z$: GOTO 7210
7250  GET Z$: RETURN

]
```

VITA AUCTORIS

1961	Born in Sibu, Malaysia.
1976	Received Sarawak Junior School Certificate, Malaysia.
1978	Received Senior Cambridge Certificate, Malaysia.
1980	Received Grade 13 diploma, Toronto.
1985	Received the degree of Bachelor of Applied Science from the department of Mechanical Engineering, University of Windsor, Windsor, Ontario, Canada.
1987	Currently, a candidate for the degree of Master of Applied Science in Mechanical Engineering at the University of Windsor.